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CONTROL OF OIL SPILLS IN HIGH SPEED CURRENTS

A TECHNOLOGY ASSESSMENT

Final Report
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16. Abstract (MAXIMUM 200 WORDS)

A technology assessment has been conducted to analyze the threat of oil spills in fast currents. Technologies and methods for response were evaluated, and promising equipment and strategies were identified. Recommendations are made to pursue those methods, equipment, and training that show the most promise for improved oil spill response capabilities in currents from 1 to 6 knots. Recommendations include technology development, testing, and field demonstrations. In addition, regulations, guidelines and training requirements for the USCG and the oil spill response industry were reviewed to determine their adequacy for fast water response. Improvements are suggested to make these practices more useful.

Containment and removal of oil spilled in rivers and coastal tidal regions, where currents exceed one knot, is very difficult because many skimmers and conventional booming methods are not effective in fast currents. Under fast water conditions, the oil must be skimmed as it goes by the recovery device, or the surface current containing the oil must be slowed down without causing entrainment within the skimmer or boom containment system. The benefits and liabilities of high-speed skimmers and specialized boom systems are reviewed for fast water conditions. Promising deflection strategies are shown. Alternate containment and diversion techniques, including pneumatic boom, horizontal air and water jets, plunging water jets, diversion paravanes, and floating paddle wheels, are also analyzed.

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PREFACE

This report describes a United States Coast Guard (USCG) sponsored study assessing the technology, strategies and training required to control oil spills in fast currents. The results and conclusions in many cases can also be applied to moving containment and skimming systems where higher oil recovery rates and faster cleanup of spilled oil are also desired. First, the spill history and potential risk of oil spills were analyzed to determine the extent of the problem on rivers and coastal areas of the US where currents exceed one knot. Typical scenarios were developed that represent those threat situations in order to identify promising equipment, strategies and training required to control oil spills more effectively in those situations.

This study identifies promising technologies and strategies that are effective to control oil spills in currents between one and six knots. This can be accomplished with specialized equipment and methods; however, properly trained response personnel and quick action are essential for success. The benefits and liabilities of high-speed skimmers and specialized boom systems are also critically reviewed. Alternate containment and diversion techniques including: pneumatic boom, horizontal air and water jets, plunging water jets, diversion paravanes and floating paddle wheels are also presented. USCG rules and guidelines for industry on the requirements for oil spill equipment were reviewed to determine if fast water oil spill control was adequately addressed.

Recommendations are made to pursue methods, equipment and training that show promise to improve oil spill response capabilities for the U.S. Coast Guard and industry in fast waters. This includes technology development, testing in controlled conditions, field demonstrations and development of more effective training techniques and field guides.

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The authors want to acknowledge and express gratitude for the many people who contributed to this report:

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The US Army Corps of Engineers (USACOE) and US Geological Survey (USGS) also assisted by providing oil transportation statistics and river current data, respectively. Of particular note is Ms. Charlotte Cook of the USACOE Waterborne Commerce Statistics Center who provided valuable database statistics of oil transported by waterway.

The American Society of Testing and Materials (ASTM) F-20 Committee on Hazardous Substances and Oil Spill Response, was very supportive to this effort by hosting a workshop on the control of oil spills on fast water during their semiannual meeting in Memphis, TN on 25 March 1998. The input provided by the thirty participants, consisting of government regulators, equipment manufacturers and end users of oil spill response equipment, was greatly appreciated.

Additional valuable input was also provided by many equipment and response experts, many of whom are listed in Appendix A.

Internal support at ManTech Advanced Systems International was also instrumental in production of this report. Of particular note is the graphics artist support provided by Mr. John Hudak who produced many of the drawings and Dr. Ronald Siatkowski who assisted with contract administration.

Executive Summary

During the past six years, 58 percent of all oil spills 100 gallons and larger have occurred in fast-current waterways. This figure represents 4.5 million gallons of oil spilled in swift flowing rivers, harbors, bays and coastal areas where conventional boom and skimmers are often ineffective. Despite these statistics, very little research and product development has been conducted on new technologies and strategies to combat this problem. Many Oil Spill Response Organizations (OSRO), industry, and the U.S. Coast Guard (USCG) are not completely prepared to respond to oil spills in these difficult and challenging conditions.

This report is an assessment of technologies and methods that have the potential to be used to control and remove floating oil from fast-water rivers and coastal areas where currents exceed one knot. Historical oil spills and fast current areas potentially vulnerable to oil spills were identified in order to define the scope of this problem. Key fast-water regions and response organizations were surveyed and visited. Scenarios were then developed in order to identify promising equipment, strategies and training required to control oil spills more effectively in those conditions. This report also identifies the most promising equipment, techniques and training currently available worldwide and recommends a course of action to improve them for the U.S. Coast Guard and industry. In addition, USCG regulations and guidelines for industry oil spill response plans and OSRO classifications were reviewed to determine if they adequately address containment and recovery of oil in fast waters. Areas that were researched and analyzed include:

Containment and Control

Traditionally, deflection booms are used to contain oil for recovery or exclude it from sensitive areas. A number of innovative technologies and strategies were identified that show the promise of being effective in fast water. These include cascade booming, the Canadian Petroleum Producers (CPP) system, boom deflectors, a current rudder, and flow diverters. Some of these methods may also be useful when deploying other systems from vessels. Problems encountered with this technology can be minimized in a number of ways and are outlined.

Recovery

Several commercial high-speed skimmers and other skimmers that were never made commercially, can recover oil at speeds ranging from 1 to 6 knots. Most, however, start to lose throughput and recovery efficiencies at speeds above 3 knots and as waves increase in height. Specialized boom systems have also been successful in fast water. Effectiveness of V-shaped boom that was procured by the Coast Guard was increased to 3 knots. The University of New Hampshire is developing a rapid current boom that uses submergence plane technology to trap and contain oil in currents up to 3 knots. Skimmers and boom systems that are effective in fast currents have also been adapted for use on ships, providing improvements in oil recovery rates.

Training

Three industry courses were evaluated to determine their effectiveness in presenting technology and teaching strategies used to contain and recover oil in high-speed currents. These five-day courses were not dedicated to fast-water oil containment and none of them covered the subject comprehensively. The Coast Guard National Strike Force (NSF) relies on these industry courses along with in-house training using Coast Guard equipment. This is inadequate due to the broad scope of the courses and lack of fast-water response equipment in the Coast Guard inventory.

USCG Regulations and Guidelines

Vessel and facility response plan regulations and OSRO classification guidelines do not address requirements specific to fast-water oil spill containment and recovery. This regulatory omission allows proposed booms and skimmers to be accepted for response plans and OSRO classifications although they are often ineffective in local high-speed current environments. Industry training requirements are vague and cursory concerning response with equipment, and do not address considerations for fast water conditions.

Significant research and development was conducted in the 1970s and early 1980s; however, very little has been done to improve the state-of-the-art in the past ten years. There is a need to develop and test promising equipment and strategies. Field demonstrations and equipment tests are recommended to perfect the technology and concepts for real-world scenarios. A technology transfer program should be formalized so that Government sponsored spill response research is made available to the public in a form that can be easily understood and used. Training should be developed that comprehensively addresses control, containment and recovery of oil spills in fast currents. Improvement of in-house training techniques, development of a field-guide, and establishing civilian equipment specialists billets at CG Strike Teams are recommended to improve response capabilities in fast-water and other oil spill response situations. USCG regulations and guidelines concerning response plans and OSRO classifications, respectively, should be revised to address response resources limited by currents above one knot and fast water scenarios that require special strategies, equipment, and training. No incentives exist for the oil industry to develop new technologies, strategies, and training methods. A change of philosophy toward efficient spill responses by government regulators, the oil industry, and the insurance underwriters is needed so that new fast-water oil spill technology and other oil spill response innovations are developed.

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LIST OF ABBREVIATIONS AND SYMBOLS

κ	Von Karman's constant (0.4)
ρ	water density
α	angle of mooring line to the current
θ	acute angle between a deflection boom and the current
D	boom draft
D	dissipation energy
d	local depth
F	force on the boom
F_c	drag force due to current in pounds per linear foot of boom profile to current
F_n	normal force on the boom
g	gravitational acceleration
H_e	hydraulic energy height
P	profile length of the boom to the current in feet
r_s	bottom roughness
T	tension in each mooring line
u	current velocity in m/s
V_c	current velocity in knots
CDR	Commander
CFR	Code of Federal Register
COTP	Captain of the Port
CPP	Canadian Petroleum Producers
cSt	centistoke
CWO	Chief Warrant Officer
DIP	Dynamic Inclined Plane skimmer
DRAT	District Response Advisory Team
FRP	Facility Response Plan
HAZWOPER	CFR defined training in: Hazardous Waste Operations and Emergency Response
hp	horsepower
LCDR	Lieutenant Commander
LOA	length over all
LT	Lieutenant
m^3/hr	cubic meters per hour or metric tons per hour
MMS	Minerals Management Service
MSO	Marine Safety Office
NSO	nitrogen sulfur or oxygen
NSF	National Science Foundation
OHMSETT	Oil and Hazardous Materials Environmental Test Tank
OSC	On Scene Coordinator
OSRO	Oil Spill Response Organization
PSI	pounds per square inch
PPE	Personal Protection Equipment
QI	Qualified Individual
RE	Recovery Efficiency
RR	Recovery Rate

SCBA	Self-contained Breathing Apparatus
SCFM	Standard Cubic Foot per Minute
SH	Substantial Harm
S&SH	Significant and Substantial Harm
TE	Throughput efficiency
UNH	University of New Hampshire
USACOE	United States Army Corps of Engineers
USCG	Unites States Coast Guard
USEPA	United States Environmental Protection Agency
USMMS	United States Mineral Management Service
VAC	vacuum, referring to vacuum truck
VOSS	Vessel of Opportunity Skimming System
WCD	Worst Case Discharge
ZRV	Zero Relative Velocity

1. INTRODUCTION

Control and recovery of oil spills in currents exceeding one knot is very difficult due to the ease with which oil entrains under booms and skimmers. Fast water also makes deploying equipment and maneuvering on the water very difficult and dangerous due to the high forces exerted on boats and recovery equipment. Although 69 percent of the oil transported on US waterways is in currents that routinely exceed one knot, very little research or product development have been conducted on new technologies and strategies to respond to oil spills in fast waters. A lack of effective fast water containment and recovery systems, mooring challenges, logistical problems and limited training and experience in these difficult and dangerous response conditions has hampered response efforts in swift currents on rivers and along coastal areas.

The limited knowledge available on this subject was mostly generated during the 1970s and 1980s. Much of this information had been forgotten and little has been applied to the field. The difficulty associated with fast water oil containment and recovery, however, is fairly well known in the oil spill response community and to some extent has created a paralysis that has stifled innovative improvements and limited response capabilities. The oil spill response industry, their customers and Government regulators do not appear very interested in equipment issues due to their emphasis on spill management, computer aids, airborne sensors, organizational structure and other response issues. This trend was verified by reviewing proceedings of the International Oil Spill Conferences for the past 25 years. Unfortunately, all the planning, forecasting and detection efforts will be to no avail if the proper equipment, strategies and trained personnel are not on site to efficiently respond, contain, and recover the spilled oil.

A. Background

Oil spills in fast water further complicate response efforts because the faster water accelerates the oil and water mixing, and oil is more prone to entrain under the boom. Since the laws of physics cannot be changed, strategies and equipment must be used to control or modify the conditions so that oil can be diverted, contained and recovered in currents. This can be accomplished using specialized equipment and strategies. The oil must be skimmed as it goes by the recovery device or the surface current with the oil must be slowed down without causing oil entrainment under the skimmer or boom containment system. It can also be diverted away from sensitive areas or to containment or recovery devices. The goal is to minimize water collection while controlling and recovering most of the oil. A lack of effective fast water containment and recovery systems, mooring problems, logistics nightmares and limited training and experience in these difficult and dangerous response conditions have hampered response efforts in currents on rivers and along coastal areas.

Recent examples of oil spills where fast-water oil containment and recovery problems occurred include: the grounding of the tank barge North Cape off the coast of Point Judith, Rhode Island, in January 1996 and the pipeline spill in the Houston Ship Channel in October 1994.

A tug caught fire off the coast of Rhode Island and was abandoned by its crew. The barge it was towing, the North Cape, subsequently grounded releasing 828,000 gallons of heating oil. Strategies and equipment were not in place to prevent oil from entering sensitive areas inside breachways. High flood tidal currents forced oil through the inlet breachways. When deep draft inflatable offshore boom was used to protect a breachway by booming straight across the inlet, the fast-water current destroyed the boom.

On 9-21 October 1994, the remnants of Hurricane Rosa brought significant rainfall to the San Jacinto River Basin causing severe flooding of the waterways in the Houston, Texas area. Thirty-six counties were declared disaster areas by the Governor. On 20 and 21 October 1994, four pipelines crossing the San Jacinto River failed due to scouring of the supporting soil. A 40-inch gasoline pipeline, a 36-inch diesel fuel pipeline, a 12-inch natural gas pipeline, and a 20-inch light crude oil line were broken and approximately 100,000 barrels of oil were spilled. As the gasoline found ignition sources, fires and explosions quickly followed. Houses, office buildings, boats, cars and barges were damaged or destroyed by the fires. Oil containment and recovery was hampered by the fires and seasonal high currents in the Houston Ship Channel and at the exit to Galveston Bay due to the flooding rains.

B. Objectives and Scope of the Assessment Study

This report is an assessment of technologies and methods used to control and remove floating oil from this most challenging environment, fast-water rivers and coastal areas where currents exceed one knot. This was accomplished by an extensive literature search, interviews with oil spill response experts and analysis of available data.

Databases and libraries were investigated for sources of information. Industry and Government experts were consulted to identify and assess applicable technologies, strategies and training techniques. A comprehensive list of research contacts used in this study is provided in Appendix A. Historical and potential oil spills were identified in order to define the scope of this problem. Key fast-water regions and response organizations were surveyed and visited. Scenarios were then developed that represented threat situations in order to identify promising equipment, strategies and training required to control oil spills more effectively in those conditions. The advantages and liabilities of those approaches were identified. Integration of methods and technologies were explored to leverage resources. USCG regulations and guidelines for industry oil spill response plans and Oil Spill Response Organization (OSRO) classifications were reviewed to determine if they adequately address containment and recovery of oil in fast waters. Recommendations were ultimately presented to improve the state-of-the art.

1. Threat

The magnitude and scope of problems unique to oil spills on fast-current waterways was investigated and defined. First, the threat of oil spills was identified and quantified. This was accomplished using available statistics of oil spills and the potential for oil spills. The tonnage of oil transported on waterways and the volume of oil stored at facilities along those waterways were use in the analysis. Historical oil spills for the past six years were identified by state and by waterway using USCG databases. Oil that was transported on waterways and through ports was analyzed using Army Corps of Engineers commerce statistics. Oil stored at facilities adjacent to waterways representing a "significant and substantial harm" were identified using data obtained from facility response plans submitted to USCG Captain of the Port (COTP) and Marine Safety Offices (MSO). Waterways that routinely had currents above one knot were then identified using tidal current tables, local area experts and US Geological Society (USGS) data. This information was then compiled to determine the amount of oil transported or stored near waterways that have fast currents. The amounts of oil spilled annually in waterbodies with currents that routinely exceed one knot were statistically analyzed for the United States for each State.

2. Scenarios

Fast water oil spill problem areas were identified and those sites were visited to obtain first hand information on valid scenarios, strategies and equipment effectiveness from the experts. This included representatives from the USCG, oil industry, response industry, cooperatives and equipment manufacturers. Government and industry experts were interviewed to gather information on the need and capabilities to respond to oil spills in high-speed currents. The literature was also reviewed to identify oil spill response challenges and lessons learned in fast-water oil spill responses. Several high-risk oil spill areas of the country were visited to see how local organizations prepare for and respond to oil spills in fast currents. Areas visited included Bellingham, Washington (Puget Sound); Portland, Oregon (Columbia River System); Memphis, Tennessee (Mississippi River); Pennsylvania (Delaware Bay); New York (New York Harbor) and Portsmouth, New Hampshire (Piscataqua River). Scenarios representing typical fast-water threat situations were developed in order to identify promising equipment, strategies and training required to effectively control oil spills in those conditions.

3. Equipment Capabilities & Strategies

Equipment capabilities were identified and evaluated using the literature, test data and expert opinions. An extensive literature search using the Internet, industry and Government libraries, conference proceedings, test reports and manufacturer data was conducted. The equipment capabilities and limitations were identified and rated. Promising containment and recovery systems were analyzed and evaluated using independent reports, when available, and manufacturer's data. A preliminary assessment of available technology was presented to oil spill equipment users and manufacturers at an American Society of Testing and Materials (ASTM) committee workshop to solicit and incorporate their input. The ratings were then revised using their valuable input. Promising technologies and strategies were compiled and evaluated. Efficient applications and limitations of equipment and

strategies are discussed. Further research is recommended for the most promising technologies including development, independent evaluation and field demonstrations, where applicable.

4. Training

Training for oil spill response on fast water currents was assessed. A survey was conducted to determine how the National Strike Force (NSF) trains its personnel for response to spills in high-speed currents. Three major industry oil spill response schools in the US have been attended by the primary author in the past seven years. One was attended during this project period. Updated information was obtained by interview with the instructors on their approach for training for oil spill response in high-speed currents. Their training capabilities were reviewed with respect to fast water oil spill response through discussions with each Strike Team and the NSF coordination center. Recommendations are presented that will improve USCG training capabilities.

5. Regulations

Coast Guard regulations and guidelines for industry oil spill response plans and OSRO classifications were reviewed to determine if they adequately address containment and recovery of oil in fast waters. Recommendations are provided to improve the requirements for spill response and training in currents above one knot.

2. BEHAVIOR AND EFFECTS OF OIL SPILLS IN FAST WATER

A. Introduction

Oil spilled on the surface of water can cause serious environmental effects to the inland and marine environments. The severity of the impact of oil depends on many factors including the properties of the oil itself. A large spill of refined oil such as gasoline may quickly evaporate and cause only a small environmental effect. Conversely, heavy oils and crude may cause long term effects by their persistence and coating effects. Oil-in-water emulsions increase the size of an oil spill and make it more difficult to contain and pump. Natural conditions such as current speed, turbulence, temperature and wind also influence the behavior of oil in water. Certain properties of oil will change more quickly in fast turbulent waters making control and recovery more difficult. Spill response efforts should attempt to take advantage of certain oil properties or changes in oil properties that occur over time. The strategy used at the start of a spill will have to be modified as the spill progresses over time as the oil properties and spill conditions change.

B. Properties of Oil

Some physical and chemical properties of oil are important to consider when developing a spill response strategy and selection of equipment. An understanding of the major oil weathering and transport processes that occur during a spill and how swift currents and other conditions effects those processes is required for proper planning and effective containment and removal of the oil. A review of spilled oil properties and processes that effect its behavior is provided in Appendix B.

1. Processes are Accelerated in Fast Water

The most obvious action that a fast current has on oil is the transport or drift of oil in the direction and speed of the surface current. This will also tend to distort the shape of the spill due to variations in those surface currents. High-speed currents necessitate a faster response to contain and recover the oil before it goes ashore. Other less obvious consequences of fast water are the accelerated effects on the oil weathering process. Figure 1 depicts the routine oil spill transport, mixing and weathering processes for slow currents[1] in solid black, while the estimated accelerated effects in fast water currents, using information compiled from this investigation, are shown in a doted outline.

Spreading is not generally affected by currents because it is dependent upon oil viscosity, surface tension, slick thickness and gravity forces. During the initial phase of a spill, the oil-spreading rate is high due to the thickness of the oil slick. A spill of 10,000 gallons will spread to a diameter of 480 feet and would be about ½ inch thick after only 15 minutes.[2] When it spreads out to a 0.0024-inch thick yellowish brown slick, it will cover 4 square miles.[1] Spreading rate decreases as the slick thins out over time. Oil drift or advection is directly affected by current velocity because oil is swept along by the surface current. Oil will be transported at the speed and in the direction of the currents until it goes ashore or evaporates. Drift is influenced by the currents and circulation anomalies

associated with the waterbody including one or more of the following: river currents, tidal currents, longshore currents, eddies, seiche currents and wind driven currents. Evaporation is a function of the surface area of the slick, temperature, wind speed and makeup of the oil. It is not affected by fast water unless related turbulence drives the oil into the water column where evaporation cannot occur. Dissolution is the process of chemical components dissolving into the water. This is based upon the chemical solubility of the oil components and the exposure to water. Fast water will quicken this process through turbulent mixing and oil entrainment into the water affording more oil/water contact for dissolution process to occur. Dispersion of oil droplets into the water column is also accelerated by turbulence. The increased surface area of oil to water resulting from dispersion increases the rate of dissolution and sedimentation. Emulsification of water and oil is accelerated by fast currents and associated turbulent mixing. Emulsified oil dramatically increases in volume due to captured water and viscosity also increases quickly making retrieval and pumping oil more difficult. Sedimentation is the processes of sediment adhering to oil. This reduces buoyancy and sometimes causes oil to eventually sink. The rate of these effects is further accelerated in turbulent waters where bottom roughness, constriction points, waterfalls and higher currents exist. Biodegradation is the breakdown of oil into water and carbon dioxide by the metabolism of microscopic oil eating bacteria naturally present. Turbulent mixing and dispersion may accelerate the process by creating small oil droplets. Photo-oxidation is the breakdown of oil by sunlight and oxygen. In some cases, turbulent mixing may reduce other processes such as evaporation and photo-oxidation since more oil will be removed from the surface.

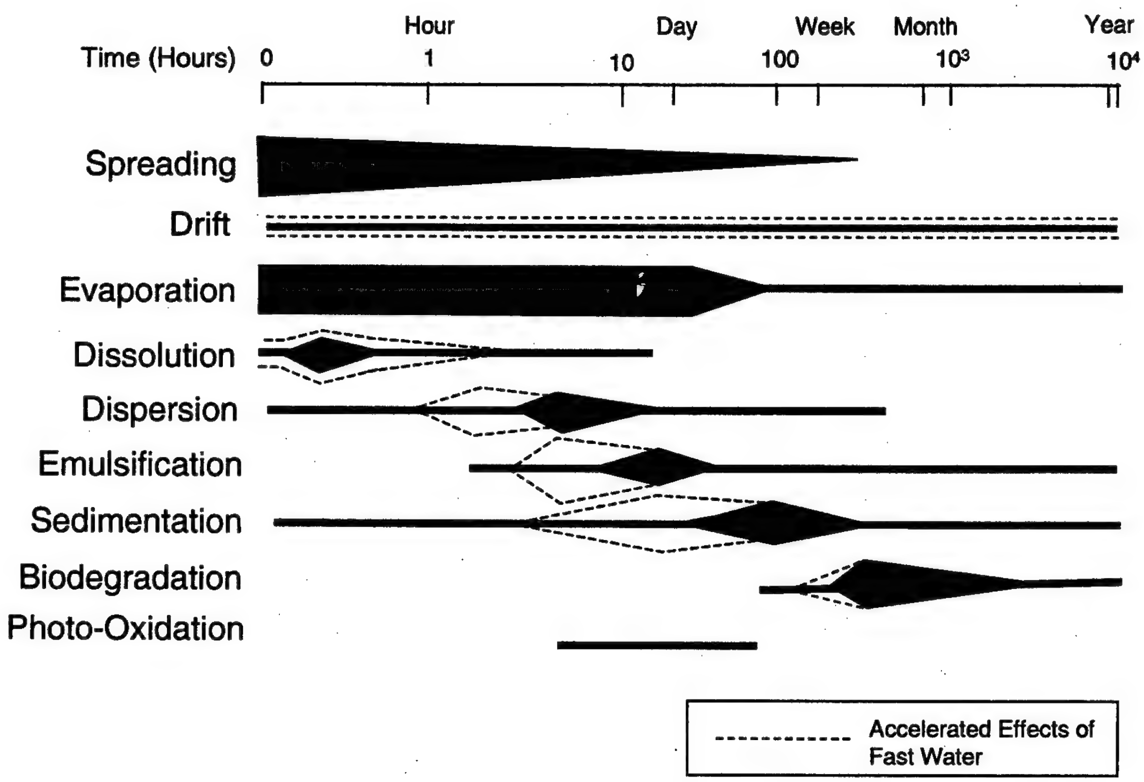


Figure 1. Oil Spill Processes and Effects of Fast Water on Them[1]

A example of accelerated oil spill processes in a fast flowing river is provided by the Norman Wells crude oil spill of 5800 gallons into the McKenzie River Northwest Territories, Canada on August 31, 1982. A computer model that predicts oil spill trajectory and fate was verified by observations made during the spill. The oil was drifting an average of 2.3 knots for the first 16 hours after the spill. The model predicted mass balance between various categories of evaporation, dispersion into the water column, shoreline stranding and remaining surface oil. It also predicted transport of the oil downstream. The mass balance predictions and observations of the spill dramatically demonstrated that a fast response was essential in order to recover the oil before it dispersed into the water column

and went ashore. As seen in Figure 2, ten metric tons or 45 percent of the oil entrained and dispersed into the water column and most of the oil that eventually went ashore (2.5 metric tons) occurred within 9 hours of the spill. No oil was observed on the surface of the water after 21 hours.[3]

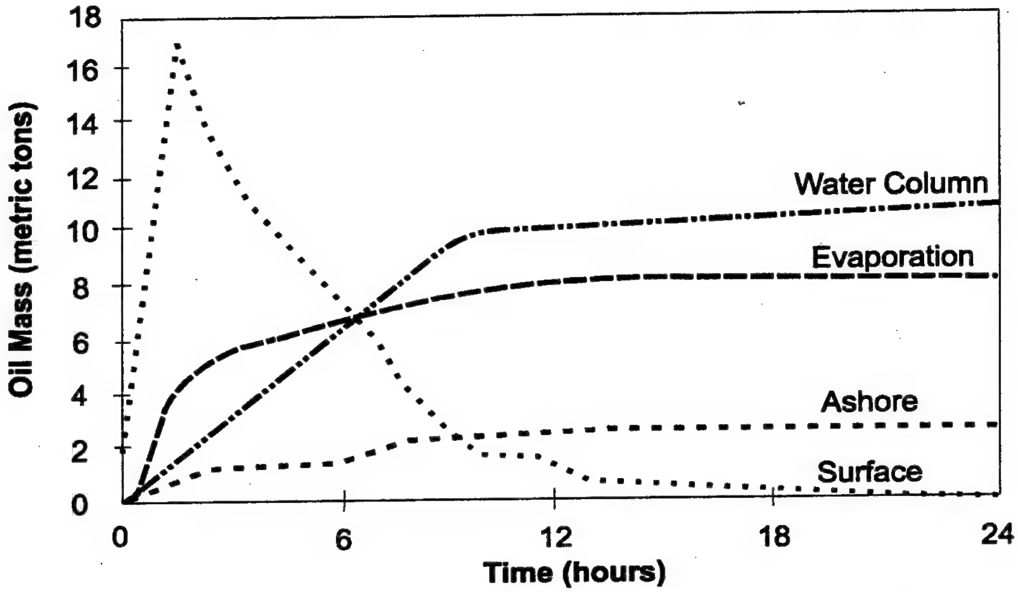


Figure 2. Predicted Oil Mass Balance for the Norman Wells Spill Event[3]

2. Effects on People, Animals and Plants

a) Overview

After oil is spilled, light aromatics, the most toxic substances, start to evaporate and the oil rapidly becomes less toxic overtime. Toxic substances however persist longer in winter climates. Toxicity is dependent upon the chemical, the sensitivity of the organism and the time of exposure. Fast currents will distribute the oil and its toxic components more quickly than stagnant conditions. This may decrease the exposure time and dose to organisms in some cases. Response personnel can be exposed to these toxic substances necessitating special precautions to minimize the potential of harmful effects. Standard practices of the initial response include assessment of the type of oil or chemical spill and monitoring of the air for flammable atmosphere, oxygen deficiencies, toxic substances and inhalation dangers. Local, State and Federal requirements specify personnel protective clothing and procedures for initial response and cleanup personnel based upon the substance spilled and local conditions.

b) Sensitivity of the Marine Habitat

Plants and animals vary widely in their resistance to the toxic portions of oil and susceptibility to mechanical damage from oil. Generally, the young and larva or eggs are more sensitive than adults are. Birds that live on the water are very susceptible to the physical affects of floating oil. Fish, plankton and mammals are the least affected. Seasonal mating and spawning times is the most critical due to the sensitivity of juveniles to the toxic effects of oil. Seaweed has a mucous coat that tends to shed oil while marsh grass does not have a natural coating and is more likely to be effected. Small amounts of oil in open areas are less toxic than higher concentrations in confined areas that may take quite a while to flush out naturally. Oil may kill organisms, disturb organisms or in some cases stimulate them. The major environmental problematic effects are:

- Direct lethal toxicity
- Sub-lethal disruption of physiological activities
- Direct physical coating
- Incorporation into the organism's body
- Alteration of the habitat

The type of oil, its physical and chemical properties all effect its behavior in the environment and the adverse effects. Table C-1 in Appendix C summarizes the major physical and chemical properties and adverse environmental effects of three major types of oil commonly spilled in water[1]. Many crude oils have all three oil types combined.

C. Limitations on Oil Containment Devices in Currents

Traditional booms contain oil by providing a physical barrier at and below the surface of the water. The boom will block flow of the surface oil and provide a containment method to prevent further spreading to shore. Booms are also used to contain and concentrate the oil into a thicker mass so that it can be more easily skimmed and removed from the water's surface. They are also used to deflect oil away from sensitive areas. Testing and experience have shown, however, that oil can escape from these containment devices by several modes, as presented in Figure 3.

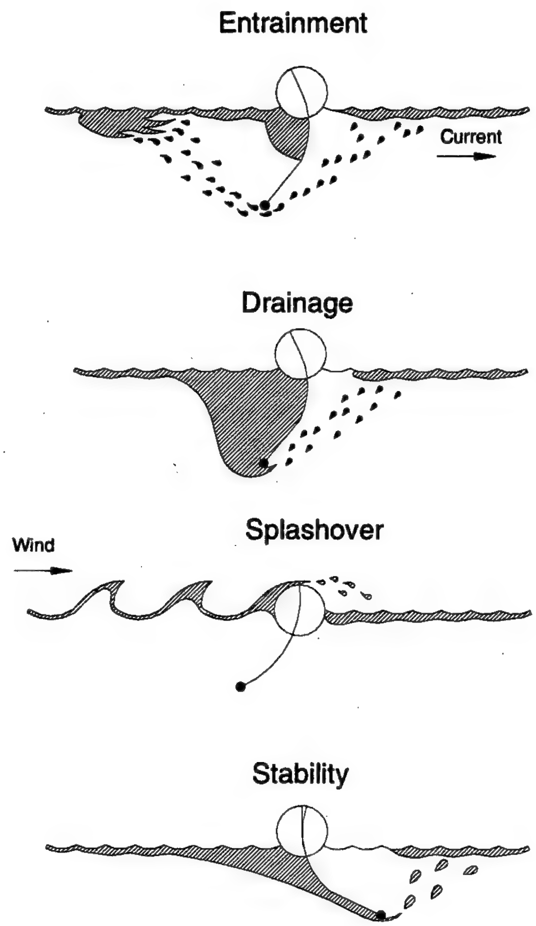


Figure 3. Four Modes of Boom Failure

1. Entrainment

Entrainment occurs when oil droplets or larger masses of the oil sheet break off and are transported under the boom by passing water. This does not usually occur in currents below 0.5 knots. This critical velocity and the rate of entrainment are dependent upon a large number of factors such as velocity differential between the oil and water, oil viscosity, oil/water density differences, interfacial surface tension and local turbulence. Entrainment occurs between 0.5 and 1.1 knots when a boom is perpendicular to the flow direction. Most sources use 0.7 knots as an average value at which oil entrainment starts. As the current velocity increases, the oil/water interface will start to deform due to hydrodynamic pressure from the passing water. A head wave will form at the leading edge of the slick within

the boom and small waves will start to form at the oil/water interface. The interfacial wave formation is dominated by viscous forces. As the water velocity increases small droplets will break off at the thickest part of the head wave and entrain in the water column. Many droplets will resurface to the oil slick within the boom but do not recombine with the slick. They will be entrained again by interfacial capillary gravity waves and follow the water path under the boom.[4] The interfacial (Kelvin-Helmholtz) waves will grow in magnitude and start to break causing more entrainment. Shear stresses on the oil increase when the waves start to form. As the velocity increases, more oil is entrained until most of the oil is lost under the boom. Local turbulence and vortices caused by a close and rough bottom, discontinuities in the boom and flow around skimmers will cause oil entrainment at lower velocities.

2. Drainage

Drainage occurs when oil builds up to a depth equal to the boom draft and starts to flow under it. The oil will then flow under the boom after it has retained all that it can within the limit of its width and draft. Fast currents can contribute to this failure mode by forcing more oil against the boom compared to no or very slow currents. High-speed booms tend to have shallow draft to reduce drag forces also limiting the amount of oil they can retain before drainage occurs. In a deflection mode, however, shallow draft will not be a factor until oil builds up in the collection pocket. This can be mitigated by skimming oil out of the pocket, double booming behind the collection pocket and use of deeper draft boom in the pocket area.

3. Splash over

Splash over occurs when waves and wind force oil over the top of the boom. High-speed currents can contribute to splash over by drawing down the boom due to hydrodynamic forces on the skirt, effectively reducing the boom freeboard. Fast moving waves will have more momentum and can push oil over a boom. Additional freeboard, higher reserve buoyancy to weight ratio and more flexible boom can all assist in limiting splash over.

4. Stability

Stability problems are caused when the boom fails to stay upright in the water or stay on the surface of the water. Wind and current contribute to this failure mode. They will tend to tip the boom out of its vertical position causing a reduction or elimination of usable draft and/or freeboard. Strong currents have been known to completely submerge a boom or sometimes cause it to plane on the surface depending upon the hydrodynamics involved. High currents demand good stability in a boom. This is generally obtained by using two or more tension members generally in the head and foot of the boom. The length of these tension members must be nearly identical to ensure the boom remains upright. Unequal stretching of these tension members will likely result in boom stability problems. External tension lines have also proven successful by using bridles attached to the top and bottom of the boom. A vertical resonance (bouncing) of the boom can develop at higher currents so selection of mooring point locations should be done to ensure the boom remains stable. Typical mooring points use end connectors with bridles to stabilize the boom. Connection at points along the boom for deflection applications should also be made at the center of the drag force or by using bridles to top and bottom tension members. Using boom with a deeper draft will usually increase stability; however, drag is dramatically increased which is undesirable in high-speed currents. Some manufacturers offer fast current boom with holes cut in the bottom of the skirt or net for the skirt to add stability but at reduced drag. This design however, may cause turbulence, thereby facilitating oil entrainment.

D. Deflection

A well known but difficult to implement solution to the entrainment dilemma is to angle the boom to deflect the oil in fast currents. As long as the normal component of the water velocity to the boom is below the critical escape velocity (approximately 0.7 knots) the oil will not entrain. Unfortunately, the boom angle must be very steep to prevent entrainment of oil when the current is above one knot as seen in Figure 4. The boom will tend to form a J-shape in a high current that will often cause entrainment where the boom deforms to an angle below the minimum required. Overlapping cascade booming can compensate for this problem. Multiple anchors can also be used to help keep the boom straight. Cupping between mooring points sometimes occurs causing discontinuities in the boom shape precipitating turbulence and eddies resulting in oil entrainment.

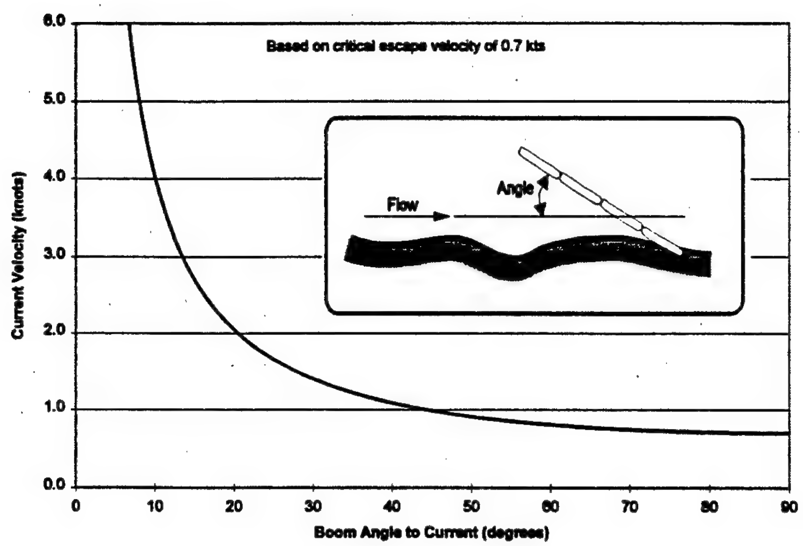


Figure 4. Minimum Boom Deployment Angles Required to Prevent Oil Entrainment.

E. Factors Affecting Selection of Shoreline Protection Techniques

Selection of the appropriate technique depends on many factors. In the case of fast-water oil spills, time is critical because the speed of oil movement is accelerated and in some cases dispersion into the water column is quickened. This necessitates prior planning to define the oil spill threats, identify sensitive areas to be protected and to select strategies on how to carry out those plans. Working with the environment should be a primary consideration when selecting and implementing containment and protection methods. Natural collection points with accessibility need to be explored ahead of time so that specific strategies and equipment required for those shoreline locations can be selected. Equipment must be pre-staged close to natural collection points and at high-priority sensitive areas for timely response. Deployment plans should use the current and shoreline characteristics to decrease equipment exposure and increase safety.

The shoreline type, its natural ability to be flushed by currents, tides or wave action and the type of organisms present all contribute to its environmental sensitivity. Endangered species sites and sensitive areas must be identified and protected. Other factors also contribute to response priorities such as protecting fresh drinking water sources, commercial water intakes, human population densities, recreational and commercial use areas and locations of historical significance. Classification of the ecological and social/economic sensitive areas should be prioritized using local agencies and experts familiar with the importance of the local ecology and economies. General environmental sensitivity, however, often follows the guidelines[1] shown in Appendix C, Table C-2. The table ranks the severity of environmental impact using an index of 10 (extreme vulnerability) to 1 (low sensitivity) which has been modified to include inland as well as coastal environments. Selection of the appropriate protection technique for a shoreline in fast water conditions depends upon many factors that are identical to other spill situations. Some issues that are different or have a greater impact for fast water situations include:

- Nature of the spill
  - Time until oil impact
  - Projected place of impact

- Weather forecast
  - Rain effects currents in rivers and water

- Type and nature of waterbody
  - River, canal, lake, marsh, swamp, lagoon, bay, ocean
  - Presence of debris or ice
  - Navigable or non-navigable waterway, traffic type and density

- Shoreline contour
  - River (winding, width, etc.), estuary, strait, headland, harbor, inlet, island etc.

- Water movement
  - Current speed and direction (longshore, rips, eddies, turbulence, submergence, etc.)
  - Tidal action: height, cycle time, reversing currents etc.
  - Wave action, wave height, wave direction, period, breaking or non-breaking, etc.

- Bottom
  - Water depth and contours
  - Bottom type (sandy, mud, rocky, reef, etc., relating to type of marine growth and anchoring potential)
  - Gradient, stability of sediment

- Man made structures
  - Piers, breakwaters, bulkheads, bridges, etc.
  - Water intakes (drinking water, irrigation, desalination, food preparation, cooling, etc.)
  - Floating houses, casinos, commercial & recreational traffic.
  - Commercial logs, cranberry bogs, fish hatcheries, fish or crustacean farms, etc.

- Available resources
  - Response organizations
  - Response equipment, type, locations and availability
  - Response personnel, their training, location and availability
  - Logistics support network & equipment

- Accessibility
  - Land accesses (bridges, roads, paths, shoreline grade, shoreline vegetation, etc.)
  - Water access (boat ramps, marinas, fuel, boat draft, specialty vehicles such as jet boats, air cushion vehicles and air boats, propulsion type, floating storage draft, etc.)
  - Air accesses (local runways, flat open areas for helicopters)

3. OIL SPILL THREATS ON FAST WATERS

A. Introduction

Oil spill threat or risk is dependent upon a combination of factors and associated importance placed on those factors. Risk is the exposure to the chance of an oil spill occurring and the significance of the consequence. USCG risk based decision-making guidelines[5] were used where applicable in this overall US assessment. An oil spill occurring in fast water is harder to manage and control making the likelihood of consequences more grave when compared to spills in currents less than one knot. Proper use of the technology and strategies available to combat fast water spills, however, will minimize the possible consequences. Fast water currents in confined waterways may contribute to an increased probability of an oil spill due to greater difficulty maneuvering and controlling a vessel and higher forces on moored vessels undergoing fuel transfer under those conditions. Mathematically, risk of an oil spill, R can be defined as:[5]

$$R = P * C \tag{1}$$

Where,
P = probability of that spill
C = consequences of that spill

The probability of an oil spill occurring is a combination of many factors such as: inadequate skills, human error, substance abuse, equipment failures, traffic conditions, weather, and other conditions such as vessel configurations

(double hull), etc. The types of spill accidents can include tank truck collision, pipeline rupture, train wreck, vessel groundings & collisions, explosions, and storage tank ruptures. Consequences are also dependent upon a combination of factors such as: type and volume of oil spilled, timeliness of notification, and response actions. Environmental conditions (water current, air temperature, wind velocity, etc.), availability of equipment and trained responders, strategies used, sensitivity of the local environment and spill impact on the local economy are other factors that effect the severity of the consequences. In-depth knowledge from local stakeholders should be used when conducting a risk analysis for specific regions/areas.

Risk management involves devoting your resources for countermeasures to prevent accidents and to effectively respond to them when they occur. The causal chain is a description of how mishaps are generated and propagated. A hypothetical error chain and possible countermeasures are shown in Figure 5.

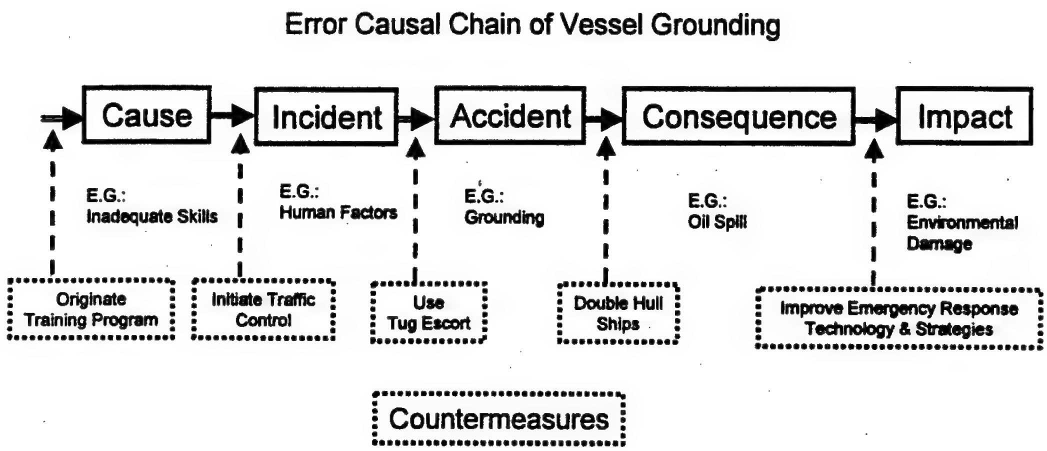


Figure 5. Introduction of Countermeasures to Affect the Error Chain[5]

In this technology assessment study, we are addressing the countermeasures that fall under the "Improve Emergency Response Technology & Strategies" category for fast water environments as seen in Figure 5 between consequence and impact. Although other countermeasures will reduce the likelihood of oil spills from occurring, they will never be eliminated necessitating improvements in emergency response technologies and strategies.

The most challenging response environment for oil spills is in fast-water currents. The probability of an oil spill occurring in that environment is high because 69 percent of all oil transported on US waterways are in currents that routinely exceed one knot. Swift currents also make vessel and barge maneuvering more difficult with a higher probability of accidents due to groundings and collisions when compared to traffic in low current areas.

B. Historical Oil Spills for the Past Six Years.

The USCG has extensive databases in their Marine Safety Management System that track many aspects of oil spills, and other marine accidents, etc., to support decision making, regulation development and policy development. Although every oil spill that is reported to the National Response Center and to local COTPs is tracked in these databases, there are not many entry categories (fields) that provide an in-depth look at the local conditions. These local condition fields are not required unless the incident is a major marine accident. No database fields were available that addressed the type of equipment, resources and strategies used during the oil spill incident. This site-specific information can only be obtained through interviews with response personnel, papers published in journals concerning the spill and sometimes in internal pollution reports.

Eleven USCG databases were reviewed to determine the type of information available to describe oil spills that occurred during a six-year period from 1992 to 1997. The major information that was extracted from these databases were case number, supplemental ID, subject, date of the spill, oil spilled in the water (gallons), oil

recovered (gallons), oil type, city, location, state, waterbody, USCG unit and District. Although the percent of oil recovered was calculated from this data, personal communication with USCG headquarters (G-MOR-3) personnel indicated that the accuracy of the recovered oil data was not sufficient to use as a performance indicator in fast water. The waterway field was used to identify where oil spills have occurred during the past six years. This provided useful information when correlated with current velocity data obtained for all major waterways from other sources. Unfortunately many oil spills in the database were identified as occurring in "navigable waters nec" when the specific waterway was not identifiable nor in the standard list within the database. This particular field represented the largest volume of oil spilled. Nevertheless, waterbodies were identified that show significant volume of spilled oil as seen in Figure 6, many of which occurred in fast water. Fifty eight percent (by volume) of all oil spills that were identifiable by location over the past six years (4,519,749 gallons spilled) occurred on waterways where the current routinely exceeds one knot. The data for all oil spills by waterway are presented in Appendix D, Table D-1.

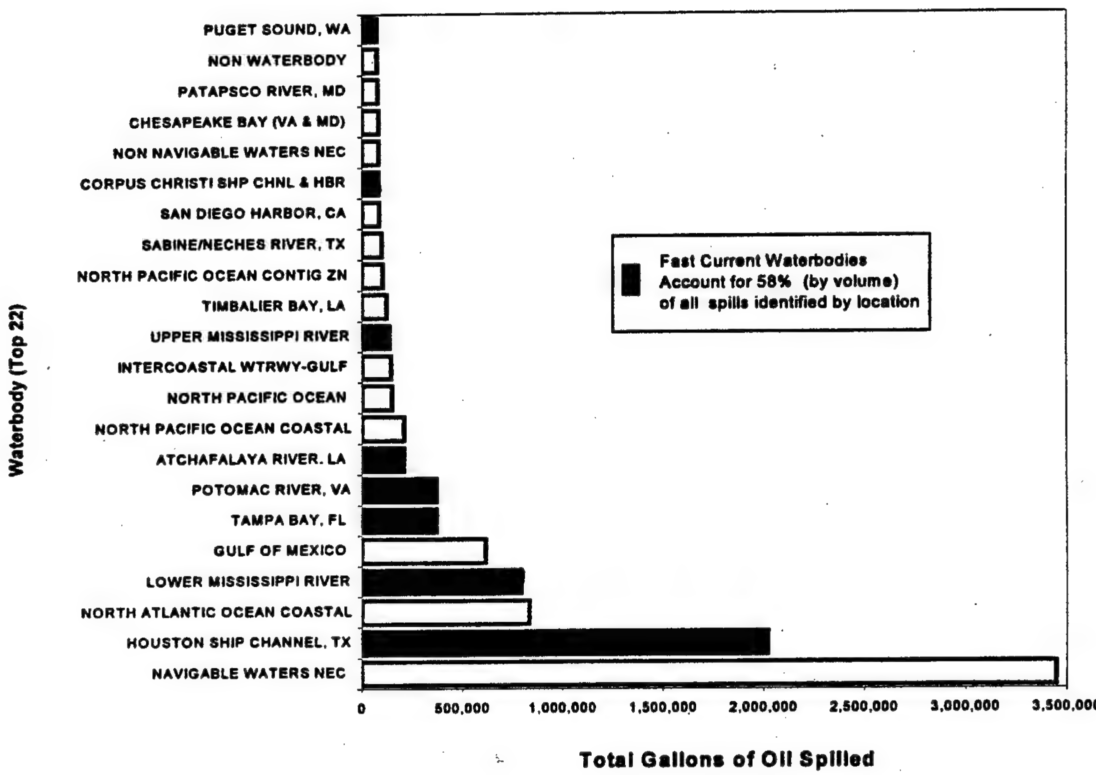


Figure 6. Oil Spills by Waterbody, 1992-1997

1. Summary of Spills by Year

Oil spill data is plotted by year for oil spills of 100 gallons or more as seen in Appendix D, Figure D-1. There is significant variation of total volume of oil spills and the number of spills per year, however, a slight downward trend is indicated. The average oil spill was 3,751 gallons. On the average, there were 564 spills annually over the past six years. The largest oil spill was 957,600 gallons.

2. Oil Spills by State and Offshore Waterbody

During the period from 1992 to 1997, Texas had the most oil spilled with a total of 2,659,611 gallons from 265 spills of 100 gallons or more. Second in volume and first in number of spills was Louisiana with 1,996,478 gallons and 458 spills. South Carolina was third with slightly less than a million gallons of oil spilled. The complete record of oil spilled by state and offshore waterbody is provided in Appendix D, Table D-2 and the top twenty two states by spill volume are plotted in Figure D-2.

C. Identification of Waterways with Fast Water Currents

The maximum ebb and flood tides from Reed's Nautical Almanacs[6] were used to characterize and define fast water coastal areas. The USACOE local offices were contacted to obtain seasonal high and mean surface current data for inland rivers. Fast-water Great Lakes rivers were identified by the USGC 9th District Office in Cleveland, Ohio. Waterbodies and Ports with currents that routinely exceed one knot were identified as fast water areas. A representative sample of these waterbodies and their associated high range currents are presented in Table E-1 of Appendix E. This fast current data is in part shown on maps of the continental US in Figure 7 below and for Alaska in Appendix E, Figure E-1.

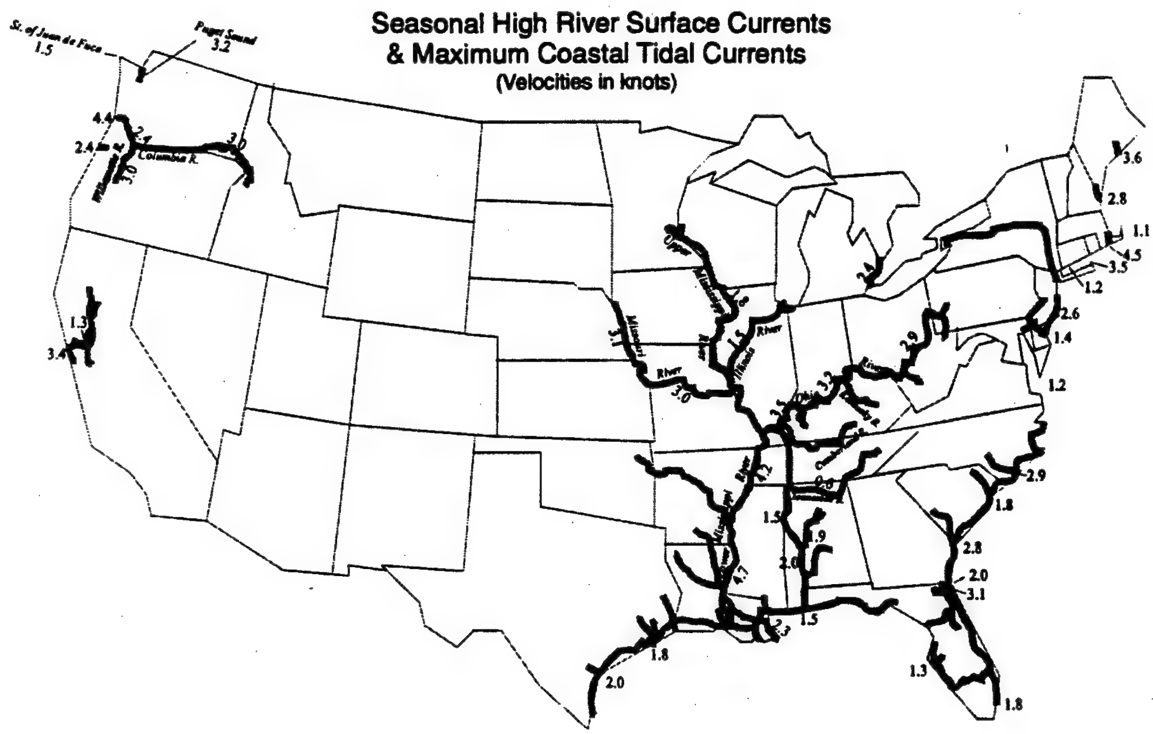


Figure 7. Fast Water Current Areas of the Continental United States

D. Oil Transportation Statistics for US Waterways and Ports

The transportation of oil by water represents a potential threat of spills. Data was obtained form the US Army Corps of Engineers (USACOE) Waterborne Commerce Statistics Center for the period 1992 to 1996. The data included domestic and foreign oil transported on all US waterways (up-bound and down-bound) and all ports (inbound, outbound and local). On every occasion that oil was moved through a different waterway or port, its mass in tons was counted because it represented a potential oil spill in that location. The average annual mass of oil transported by waterbody and port was calculated as seen in Appendix F, Table F-1. Ports and waterbodies were selected so that no overlap or double counting of oil transported occurred. Whenever possible consolidated reports and waterway systems were used to reduce the number of records processed. Waterbodies with less than 10,000 tons transported annually were not included. Oil transported on all US waterbodies and in ports was determined to be 931 million tons annually. Oil transported on waterbodies and in ports with currents that routinely exceed one knot was compiled and totaled 645 million tons annually. Oil transportation on fast water was 69 percent of all oil transported in US waterways and ports.

E. Facility Response Plan Data for US Waterways

Between 1992 and 1993, facilities contributed 24 percent of the oil spilled into waterbodies according to USCG statistics. The threat of oil spills on inland and coastal US waterways can be assessed by measuring the quantity of oil stored at facilities adjacent to them. This was determined by collecting oil storage information of river and

coastal-based facilities at twelve representative regions from a sampling of Coast Guard MSOs. Each MSO holds a Facility Response Plan for the facilities within its area of responsibility. Within the Facility Response Plan is an estimate of a facility's worst case discharge (WCD) of oil. This volume of oil was chosen as the indicator of a facility's oil spill threat. The WCD is the total amount of oil spilled from the start of the spill to the point at which all lines and tanks are secured, plus any oil in the drainage lines. This collection covers 234 facilities, with an average WCD of 4,600,000 gallons per facility. The formula used to compute WCD and a complete listing is of the facilities sampled are provided in Appendix G. Table G-1 includes facilities, locations, WCDs and the facilities' respective waterbodies.

F. Areas of Concern (Fast Water and Significant Oil Spill Threat)

As demonstrated from the six-year history of oil spills, waterborne oil transportation statistics, and facility oil storage data, there are may areas that represent significant threats of oil spill where currents routinely exceed one knot. In many of these areas currents exceed 3 knots. Virtually all the inland rivers and a significant number of coastal ports and harbors have high currents as seen in Appendix E, Table E-1. Unfortunately, these fast-current waterways are also the major oil-transportation routes. They are present in every geographic region of the United States. Of particular concern are the top nine fast-water ports and waterways that have major oil tonnage transported on them each year, as seen in Table 1. Many other fast-current waterways also represent a significant threat for oil spills. Oil spills from pipelines, train derailments and highway traffic accidents adjacent to waterways also pose a threat, but they were not analyzed separately.

Table 1. Top Fast-Current Waterways Used for Oil Transportation

Oil Transported On Major Fast-Current US Waterways*
Average Annual (1992-1996)

Waterway	Oil (tons)
MISSISSIPPI RIVER SYSTEM	99,748,242
DELAWARE RIVER, (Trenton, NJ to the sea)	91,438,848
PORT OF NEW YORK (Summary)	85,558,941
VALDEZ HARBOR, AK (Prince William Sound)	84,469,900
HOUSTON SHIP CHANNEL, TX	76,869,681
CORPUS CHRISTI SHIP CHANNEL, TX	51,086,019
SAN FRANCISCO BAY ENTRANCE, CA	41,903,729
PASCAGOULA HARBOR, MS	20,962,514
OTHER PUGET SOUND AREA PORTS, WA	19,686,693

* Waterways with currents that routinely exceed one knot

4. FAST WATER OIL SPILL SCENARIOS

A. Introduction

Oil spill scenarios are outlines or scripts of probable conditions and situations that are used to plan strategies and prepare for the proposed emergency response. A review of published oil spill data and information was conducted for fast water areas that have a significant spill threat. Case studies and lessons learned published in all the International Oil Spill and Arctic Marine Oilspill Program (AMOP) conference proceedings were analyzed. Oil spill and oil transportation statistics for fast water areas were evaluated. Important fast water scenario sites were visited to determine how industry and Government prepares to respond to such oil spills. Particular conditions were identified that make fast-water oil spill response unique and challenging. Promising strategies, equipment and training methods were identified from those sources.

The goal of fast-water response is to control, contain and remove oil as fast as possible before it contaminates shorelines and sensitive environmental areas. Typical fast-water scenarios were developed that represented those threat situations in order to identify promising equipment, strategies and training required to combat oil spills more

effectively. Preliminary fast-water scenarios were developed and presented to USCG Headquarters and the National Strike Force (NSF) for comments. Refinements were made to develop scenarios that represent the wide range of oil spill conditions in fast water regions throughout the US that are likely to occur. These scenarios were used to investigate and develop response strategies that are effective in those conditions. Containment and recovery equipment was also identified that would be effective in those conditions. Limitations of present technologies and strategies were also identified to target areas that need more research and development.

B. Typical Environments Effected.

The scenarios either involve a coastal salt or brackish water environment or a fresh water river situation. Each has unique physical structure, associated configuration and environmental concerns. Coastal areas have the added problem of reversing tides and salt wedge intrusion dynamics. They both have some commonalties as well. Understanding the anatomy of the spill area is required to develop a proper and effective protection strategy. Knowledge of the hydrodynamics and physical characteristics of the waterway as well as the environmental sensitivities are also required. Descriptions, unique characteristics and environmental sensitivities of specific types of freshwater and coastal areas concerning spill response considerations are presented in Appendix H

C. Fast-Water Scenarios

Incorporating local environmental factors and physical constraints of the waterbody to be protected in contingency planning or response operations is important to ensure the response is realistic and practical. Environmental sensitivity of various areas will determine the response priorities. Environmental parameters such as nearshore circulation patterns and current velocities should be take into account with the physical layout of the shoreline when developing spill response tactics. These scenarios address many of the considerations and situations that will require consideration in selection of equipment and strategies in fast-water oil spill response.

1. Fast Current Navigable River Scenarios

Navigable rivers support a high volume of commercial oil traffic, they are often characterized by high currents and turbulent waters, making it difficult to respond to oil spills. During the two-year period of 1992 to 1993, twenty percent of all oil spills occurred on rivers and canals. This represented the highest percentage of all waterbody categories and it is equal to that of the Gulf of Mexico. The Mississippi River system accounts for more oil transported than any other waterbody in the US, at 100 million tons per year.

Large oil spills on fast navigable rivers very often require that vessel traffic be stopped while the response is in progress. Strategies that allow vessels to pass are desirable because they mitigate the economic losses to the region during protracted spill responses. The oil tends to mix in the water column quickly due to turbulence. Oil in this environment forms an emulsion quickly increasing the volume of oil/water to be recovered and making skimming and pumping much more difficult with a much higher viscosity. Navigable rivers will generally have a depth greater than 6 feet and most channels will have depths in excess of 20 feet. Depths of more than 40 feet are found in harbors and near the river mouths. The swift current, deep channels and wide banks make oil diversion booming, containment and skimming very difficult. Rivers near the coast have an added complication of reversing tidal currents.

a) No Tides

Ocean tides produce oscillations upriver in estuaries open to the sea. The tidal stretch and associated cyclical tidal currents are governed by the height of the riverbed relative to the high tide level, river outflow and local topography. Tides are not a factor on inland rivers above a point that the riverbed slope exceeds the high tide range. This makes response a little more manageable because the entire flow of the surface currents does not change direction in a cyclical manner. There will still be reverse flow on inland rivers in eddies and possibly in some backwater inlets and tributaries depending upon the hydrodynamic forces and wind driven currents at work. These reverse flows will remain constant during the response unless rain increases the water level or strong winds dramatically shift. Inland rivers can routinely have currents from 3 to 4.7 knots, as seen in Appendix E, Table E-1. During peak seasonal flooding, the Mississippi River can attain velocities greater than 9 knots making it one of the most challenging response environments. Published currents are difficult to find and are not generally accurate as a predictive tool due to the variable water runoff. The USGS has quite a bit of near real-time river stream flow and stage height data available through the Internet that will help with response planning. They also provide the data in graph form along with historical averages. Seasonal trends provide general high current periods. Local knowledge or river cross

sectional area data, however, is required to convert stream flow (cubic feet per second) data to surface velocities for a particular river station. Depth of navigable rivers will vary significantly along the route and is dependent upon the flood level.

The strategies available for use are dependent upon the specific conditions at hand and available resources. Boats are required for response on large rivers. Mooring systems for deflection booms will have to be substantial to withstand the high forces. Deflection booming is used to keep oil away from water intakes and environmentally sensitive areas. Oil is usually diverted to slower current areas near shore in natural collection pockets or inlets where conventional low current skimmers will be effective. Oil can also be skimmed out on the river with high current skimmers attached to vessels of opportunity or integrated into dedicated response vessels. Boom can also be used to encircle the large oil patches while moving with the current. The oil is then slowly diverted at a velocity less than one knot relative to the surface current into a low current eddy or inlet for skimming. Locks and canals found on many inland rivers can be used as convenient containment areas. During peak flood periods, however, they cannot remain closed or water may flood the upstream banks forcing oil into wetlands or inland areas.

The following oil spill event is provided to demonstrate the type of spill that can occur on a navigable river. A Barge hit a dam abutment on the Arkansas River releasing 336,000 gallons of No. 6 fuel oil on June 27, 1982.[7] Sixty miles of river were affected including recreational, industrial and wildlife refuge areas. The current was unusually high, at 5-7 knots (1.4 million cubic feet per second), and most likely contributed to the accident. The oil had a specific gravity of 0.967 that facilitated mixing due to its limited buoyancy. The responsible Party: Apex Oil Co. declined its removal obligations and the On Scene Commander (OSC) initiated the pollution fund. Oil eventually extended with a sheen 60 miles (10 hours downstream at 6 knots) to the Mississippi. Navigation of the river/lock system was stopped during the response. Boom was deployed at the White River National Wildlife Refuge and at entrance at lock dam 3. Several inlets were heavily oiled. Currents made booming difficult and ineffective. The first 18 miles were heavily oiled which means that most of the oil went ashore during the first three hours of the spill. High water volume forced the locks to remain open so they could not be used as an oil barrier. Seven agencies responded for over 25 days and spent $372,000 on the response. This spill demonstrates that in extreme conditions pre-staged equipment and trained personnel are required to quickly respond to protect sensitive habitats. Good strategies and the proper equipment are required to ensure booming is effective in high currents.

b) Reversing Tides

The presence of tides on a navigable river will significantly complicate an oil spill response. Approximately every six hours the tidal currents will change from maximum flood to maximum ebb tide. This requires constant tending of the deflection boom and often means that the equipment must be repositioned on each tidal change. Maximum currents in fast water tidal rivers vary between 1 and 3 knots as seen in Table E-1. The ebb current is usually slightly stronger than the flood tide due to fresh water runoff and rain can dramatically increase it even more. Tidal current charts are accurate, however, local conditions can dramatically change the time and magnitude of maximum currents and slack water. Strong winds can pile up water against coastal areas and accentuate high tides or reduce low tides depending upon the time and direction that the wind is blowing.

Inlets, attached bays and tributaries are generally sensitive areas that must be protected during flood tides to prevent oil from entering. Oil that has been collected during an ebb tide by a diversionary boom angled to the shore will be lost on a reversing flood tide unless it is skimmed or contained from escaping. Booms often have to be moved as the tide starts to shift in order to protect sensitive areas or contain oil during the flow reversal. If the boom is to remain in the same position during both tides then it should be anchored on both upstream and downstream sides to keep it in place an to prevent anchor dislodgment. More boom and mooring systems are often required in tidal change areas in order to protect sensitive areas during both tides.

2. Coastal Tidal Current Scenarios

Coastal tidal currents also complicate oil spill response outside the mouth of rivers, salt marshes, harbors and bays. The circulation patterns are effected by the changing shoreline, bottom depth, longshore currents, islands, deltas, etc. Tidal currents are generally lower than inland river currents, however, they can exceed one knot, making oil containment difficult. The most challenging areas are at the mouth of inlets where velocities increase and directions change. This makes it even more challenging to predict oil spill trajectories in order to protect coastlines. If oil is

originating from an inland waterbody source, it can be swept down the coast to new areas or return to the originating waterbody depending upon the local tidal current conditions.

Oil drift and fate models can assist with the planning process. During a spill, local knowledge of circulation patterns, visual observations and measurements are often more useful than drift models that use average historical data. Computer models need to be validated using drift studies. Oceanographic survey data should be used to define local currents for use in planning and updating computer models. Ideally, models will allow for real-time current data and spill trajectory updates during a spill response.

Spills originating on the ocean or along the coast are in danger of impacting the coastal area or entering inlets where areas that are more sensitive exist. Water depth is usually greater along the coast than in rivers and bays, thus requiring more anchor chain and line to moor boom. Open sea conditions bring the potential for higher wind-driven waves and swells. This will necessitate the use of larger freeboard and deeper draft boom. Higher drag forces on deep draft boom will complicate the response in fast water by deforming the shape of the boom requiring more anchor attachment points along the boom and larger anchors.

a) Moderate Waves and Wind

Waves are a major factor in coastal response because they make containment difficult and reduce the efficiency of skimmers. Wave energy is more prevalent in the mid and northern latitudes of the east coast, Great Lakes, north west coast and Alaska waters. Short choppy waves make containment and recovery more difficult compared to long period swells. [8] Incline submergence plane and oleophilic skimmers are more effective in waves than surface-slicing weir skimmers as discussed in the oil recovery section. Self-adjustable weir lips follow wave motions and maintain efficiencies in waves. The effectiveness of a boom in waves is dependent upon many factors that also include wave conformance, flexibility and hydrodynamic stability. Tests of offshore oil booms has show that a reserve buoyancy to weight ratio of at least 20 to 1 is required in high seas states offshore. Boom diversion systems will amplify waves making skimming more difficult.

Wind effects must be included in any containment strategy. Wind shifts will change the drift direction and speed of oil spills. Typically, oil will move at 3.5 percent of the wind velocity. High winds may also cause boom to lay over facilitating splash over and premature drainage due to reduced freeboard and draft respectively.

b) Harbor Protection from an Ocean Spill

There are several options to protect a harbor from an ocean or coastal spill from entering during a flood tide. This scenario is quite common in the Gulf of Mexico where approximately 20 percent of all waterbody spills occurred along the coast during between 1992 and 1993. Nationwide during this period, 13 percent of all oil spills occurred within 12 miles of the coast. Containment and recovery of the oil where it has spilled is the highest priority. The sooner a spill is contained, the less area it will cover drastically reducing the equipment and personnel required. This is difficult to accomplish for any spill and it is further complicated for ocean spill responses by logistical delays and bad weather that may be encountered. The next line of defense is to deflect oil past the harbor entrance. Generally, this is more effective when conducted away from the main current into the harbor. Oil can also be trapped and contained by setting up diversion boom to deflect oil to the shoreline outside the harbor entrance. Longshore currents may be helpful since they can transport oil along the coast into collection booms that are properly placed. Large waves may hamper or prevent diversion to shore along the exposed coast so it may also be necessary to contain and divert oil in the entrance of the harbor. This can be accomplished with open chevron booming to allow vessel passage. High currents in the entrance may necessitate booming in the open areas just inside the harbor where currents are slower.[9] The oil can also be contained and recovered by Vessel of Opportunity Skimming Systems (VOSS) and dedicated response vessels along its drift path toward and into the harbor.

c) Barrier Island Breachway Tidal Inlet

A classic estuary is protected by long sandy barrier islands as found along the coast of North Carolina and Texas. A large body of water exists inside the barrier islands that is often fed by one or more rivers and is partially flooded each tidal cycle. The narrow inlet is often used by recreational boaters and commercial fisherman. Tidal currents on maximum ebb and flood will usually exceed 4 knots in the inlet. Flood and ebb deltas complicate circulation patterns inside and outside the inlet respectively. Steps need to be taken to contain and skim the oil offshore where

the currents are lower, yet waves are higher. The inlet must also be protected near the entrance and inside the lagoon.[10] A typical flood tide strategy[10] is shown in Figure 8.

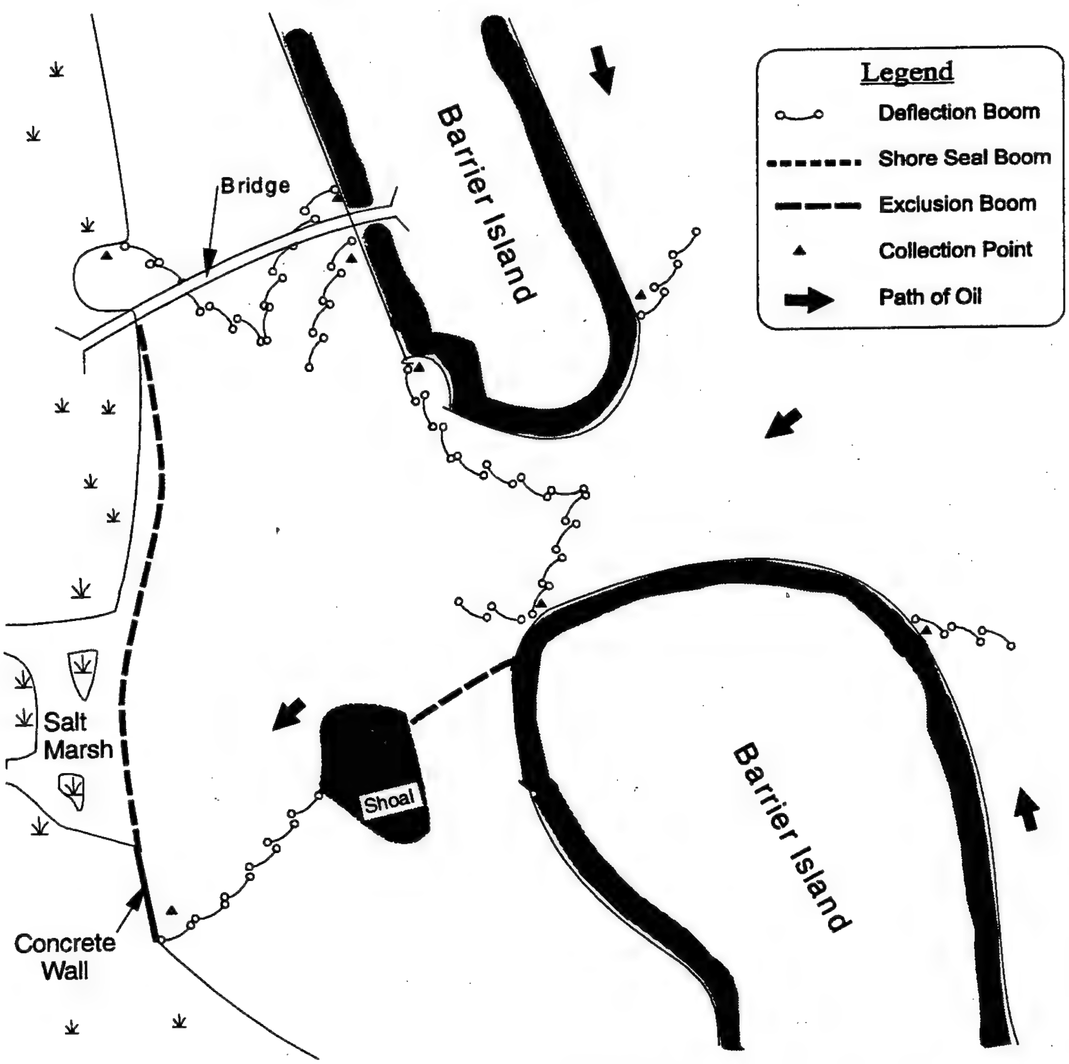


Figure 8. Typical Flood Tide Strategies used on a Barrier Island Inlet[10]

3. Large Open Bay with Reversing Tidal Currents Scenarios

A large open bay with reversing tidal currents is protected in a fashion similar to harbors. The area to protect is larger with more inlets requiring booming on the flood tide. An open bay with a longer fetch invites the formation of higher waves that require larger boom and boats. Containment of oil in open areas is more likely to be successful than near shore. Exclusion booming is required for inlets and sensitive coastal areas. Examples of this scenario include the Delaware Bay, Chesapeake Bay, Long Island Sound, Puget Sound and Prince William Sound. Delaware Bay and Prince William Sound both have 85 million tons of oil transiting through them each year while Puget Sound has 20 million tons transported. This presents a high risk for potential oil spills. During the two-year period of 1992 and 1993, eleven percent of all oil spills occurred in bays and sounds. Tidal currents vary in these large areas but maximum flood and ebb tides range from 1 to 2 knots with higher velocities at choke points and inlet entrances.

a) Protection of Wetlands and River Mouths during a Flood Tide

The highest priority in large bays and sounds is to protect wetlands, river mouths and sensitive coastline from oil intrusion. This is most critical on the flood tide when fresh water runoff is insufficient to prevent oil entry.

Chevron exclusion booming is used to protect sensitive islands and points. The primary method used to prevent oil entry into inlets is exclusion booming at steep angles. Cascade diversion booming and containment is used to divert oil to shore at natural collection points with good access. Fast-water skimmers can also be placed at the apex of V-shaped boom in high currents located inside inlets as a secondary defense. Salt marshes and tidal flats can also be protected using a shore-sealing boom with three chambers. The top chamber is inflated with air while the two adjacent lower compartments are water-ballasted. At low tide the boom seals to the shore and remains upright. Shore seal boom can also be used as the first section of boom in a diversion system to assist with excluding oil from areas with large tidal height change, Figure 9.

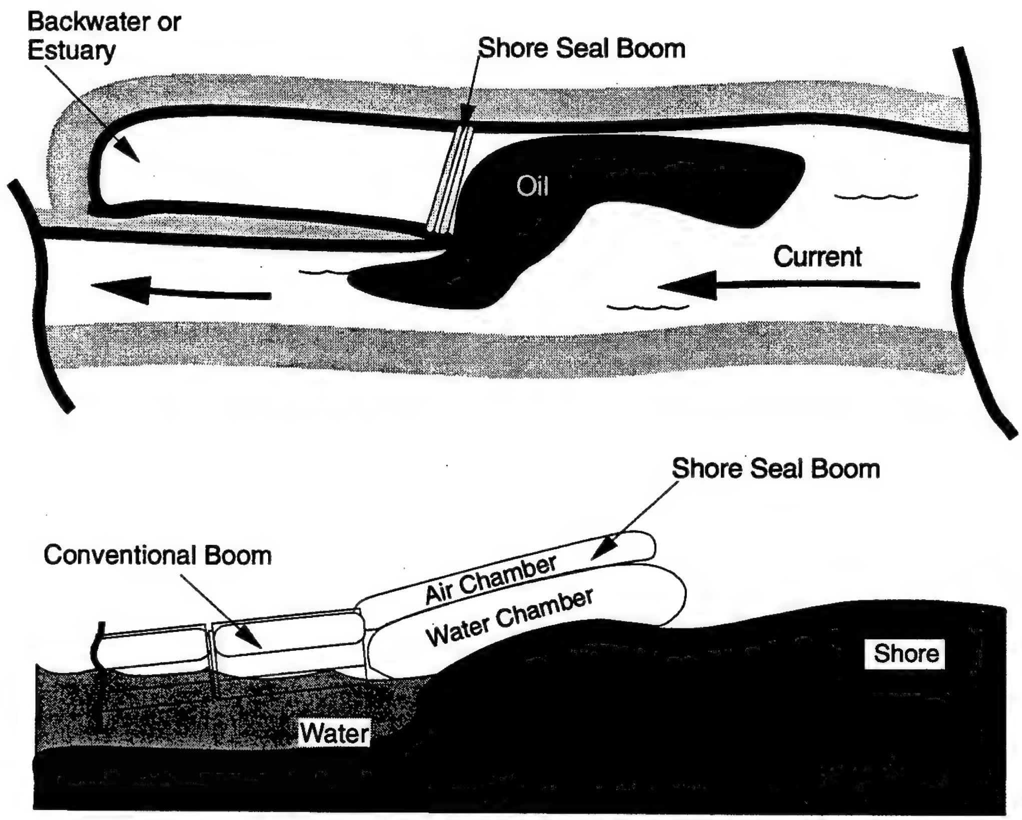


Figure 9. Two Uses of Shore Seal Boom in Tidal Areas

b) Containment and Recovery in an Open Bay

Oil concentration, containment and skimming can be accomplished in an open bay or sound with VOSS and dedicated response vessels. Like coastal responses, larger boats and booms are required due to high waves. Various oil consolidation techniques such as using large V-shaped boom can be effective at concentrating oil into rows for trailing or attached skimmers. A combination of open area containment and recovery along with shoreline protection is usually required for large bays.

4. Shallow Narrow River or Culvert Scenarios

A shallow river with a water depth of 2 feet or less is considered non-navigable for commercial transportation. These waterways usually have moderate to high sensitivity environments due to their habitats and a small dilution factor for spilled oil. They are susceptible to oil spills from pipelines, storage facilities, train derailments, highway accidents and storm drainage sources. Access is often difficult due to lack of roads, dense brush or steep banks. Since a small amount of boom and light weight skimmers are required on narrow river (less than 600 feet wide) responses, this equipment can be staged in boxes or baskets and air lifted by helicopters for quick response. Cascade booming is used to deflect oil to shore where currents are slower and low current skimmers can be used. Problems can occur when the boom draft exceeds one third of the water depth. This will cause entrainment even when steep

diversion angles are used due to turbulence and increased water velocities under the boom. Very shallow draft boom and alternate diversion methods such as horizontal water or air jets and flow diverters may be effective to control oil in fast shallow water. Underflow dams can be used in small streams and culverts for exclusion or containment of oil if equipment and people are available to construct the dam.

D. Other Scenario Considerations

1. Debris Scenarios

Floating debris on rivers and in tidal bays is a major problem during oil spill containment and recovery. Large debris in fast-water currents above one knot will often damage and displace diversion booms. This is most critical when rain flooding conditions or seasonal high tides float debris from previous storm-surge wash lines. In the Pacific Northwest logs can be oiled and cause economic losses for the logging industry as well as dangerous debris problems for response personnel and waterborne equipment. Small debris is also a problem because it will block flow to skimmers and jam pumps. Some skimmers use debris screen and others have positive displacement pumps can process a certain amount of debris with the use of cutting blades. Some dedicated oil skimming vessels have debris baskets and grates that assist with handling debris. Oiled debris will continue to release oil causing an extended response effort. Removal and disposal costs of oiled debris often equals and sometimes exceeds that required for the oil alone.[11] Strategies are required to contain and remove oil in fast currents with both heavy and light debris. Methods to minimize the oiling of debris and to effectively handle and process this oil-coated debris are presented below.[12]

- **Double barriers:** Two barriers are deployed in parallel. The first barrier retains debris only while the second barrier retains oil in the quiescence zone between them.
- **Protective barriers:** An upstream barrier that allows water and oil passage but retains debris such as snow fence, chain-link fence and chicken wire can be used with added floatation and ballast or they are attached to the existing boom.
- **Diversionary booming:** Deflection boom is deployed and an angle to reduce the impact damage from debris. Booms deflect debris and oil to calm water areas for removal and disposal.
- **Manual tending:** Debris trapped in oil pockets and next to skimmers is removed manually.
- **Debris handling equipment:** Cranes, front-end loaders, trucks, barges, automated water intake debris screens and specialized debris handling boats are used for removal of big items and large quantities of oil-soaked debris
- **Diversionary water jets and propeller wash:** The current moves debris away from collection points.
- **Debris and logjams:** Diversionary containment boom can be positioned downstream of the jam and collect oil that entrains under the jam.

a) Debris Transportation

Transportation of debris is accomplished with trucks, boats, barges and sometimes aircraft. The debris must be put in watertight containers or wrapped in plastic to prevent further oil leakage during storage and transportation. Debris can be incinerated near the collection site when a permit is granted.

2. Winter Response Scenarios

Fast water response in winter conditions is the most difficult due to the additional problems of cold temperatures, ice and frigid water. Personnel fatigue will set in much more quickly in cold weather conditions. The amount of daylight available is limited or nonexistent in the winter depending upon the Latitude location. Oil is difficult to track and contain in icy conditions. Higher oil viscosity makes it difficult to skim and pump oil. Certain techniques and equipment however, are effective in these difficult conditions.

a) Broken Ice

Broken ice is treated like floating debris as discussed above. A large mass of broken ice can pile up on the boom greatly increasing load forces that can damage the boom and pull out mooring anchors. Inflatable boom is susceptible to punctures from sharp corners on the ice, so foam-filled boom or rigid structures are recommended. The coverage of broken ice on water may prevent the use of conventional boats. Air cushion boats and airboats can

be used on broken and sheet ice to move equipment and people over the ice and water. Specialized ice deflection structures have been developed that allow oil to pass through while deflecting large broken ice around them.[13] The structures have deflectors on the downstream side such that they position the barrier into the current without the use of a downstream anchor. Conventional diversion booms can be then used in the lee of this type of device to collect the oil. Boom fabricated from logs have been used in a diversionary mode to create a clear area for oil containment with conventional boom downstream on small rivers with light ice cover.[14]

b) Solid Sheet Ice

Whenever working on ice sheets proper safety precautions should be used. A gasoline driven chain saw, trenching machine, circular saws and auger drills are often used. Exploratory holes should be drilled to determine the proper bearing capacity of the ice sheet using the appropriate safety chart. A current meter can be inserted into these holes sequenced across the river to determine the current profile for selection of the proper boom and slot diversion angles to prevent oil entrainment. Oil velocity under and adjacent to the ice is less than the average water velocity below it. Faster currents and more shallow rivers cause the oil velocity to be closer to that of the water current. For example, in a one-knot water current with a 10-foot deep river, the oil will be transported at 25 percent of the water velocity. At two-knots the oil will be moving at 55 percent of the water current velocity.[15]

The technique of cutting long slots approximately four feet wide through the ice sheet 28-inches thick at a 30-degree angle to the current has proven to be an effective method for capturing oil flow under an sheet in a one knot current.[15] The oil then flows down the slot to the downstream end where it can be recovered with a skimmer. This configuration with 28-inch thick ice was able to hold about a five-inch layer of vegetable oil on the surface without loss in a one knot current. A second slot angled to the opposite side of the river will provide complete coverage. The effectiveness of oil collection in slots cut in thin ice in the field is unknown. Cutting slots in thin ice, however, will alter its structural properties and should be done with extreme caution.

Plywood can be used as diversion booms in sheet ice. Two 2 by 4-inch boards are nailed on opposite sides along the length of the sheet at the desired height of the boom. A diversion slot is cut perpendicular to the ice sheet slightly larper that the width of plywood sheet thickness. The sheets are then slid into the slots so that it extends approximately one foot into the water below the ice. This technique can be used to divert oil into the ice slot described above or to shore where the ice is cleared for collection and skimming operations.

5. OIL SPILL CONTAINMENT

A. Introduction

Containment of an oil spill is the most important initial action. It stops the oil from spreading and impacting the shoreline and other sensitive areas. The ability of a containment system to accomplish this in the environment of fast flowing water is dependent upon the containment method, equipment, strategy and implementation by trained personnel. Traditional containment systems consist of many different types and configurations of booms. There are also many other alternate methods including: pneumatic boom, horizontal air and water jets, plunging water jets, diversion paravanes, and floating paddle wheels that are critically presented. Containment becomes more difficult as current speed increases. There are three main functions of containment or oil control systems:

- Containing oil and preventing further movement and spreading.
- Concentrating and thickening oil slicks to aid in recovery and improve skimmer efficiency.
- Protecting sensitive areas by diverting or excluding oil from a specific area.

B. Hydrodynamics

The flow and behavior of oil and water are the major consideration when selecting the containment system for the specific environment at hand. Entrainment is the single most important phenomenon to be concerned about in order to effectively control and recover oil in currents above one knot. The strategy selection process and the successful implementation of that strategy to minimize entrainment hinges on understanding the circulation patterns of that waterway.

1. Reading Currents and Flow Patterns

Selection of a good location to deploy the oil containment system is dependent upon prior planning and understanding of the currents. Drift studies, oceanographic surveys, tidal current tables and charts, and computer modeling are all useful tools to understand the flow patterns and to develop strategies. The day of the spill, however, may present a different current and circulation pattern or other factors that require accurate field observations. Reading the currents and flow patterns require practice and understanding of the hydrodynamics involved. Several things may be helpful to define these patterns.

Selection of a containment area with a lower current is desirable if available. This will reduce the deflection angle required and reduce drag forces on the boom. Lower current will also permit faster and safer deployment of equipment. The current velocity profile can be estimated by observing debris floating by and observing turbulence. Current meters can be used to measure these flows, but they require an anchored boat or bridge to deploy them so they are usually not practical during a spill response. Using a chip log can be very effective and only requires floating debris, a tape measure and stopwatch. Current speed can be calculated by timing the movement of floating debris over a measured distance. Velocity in knots can be calculated by dividing velocity in feet per second 1.7, Figure 4, is useful to determine the minimum deflection angle required for a measured velocity.

C. Boom

Boom is the primary method used to contain oil. There are many different configurations and types of boom. Each boom, however, has certain attributes associated with it.

- **Freeboard:** the height above the waterline that resists splash over.
- **Draft:** the depth below the waterline that contains oil consisting mainly of the skirt.
- **Flotation:** provides buoyancy for the boom.
- **Tension member(s):** provide additional strength and dynamic stability to the boom.
- **Ballast:** (optional) provides a counterweight to keep the skirt vertical.

Other auxiliary components can include:

- Anchor points
- End connectors
- Hand holds
- Lift points
- Stiffeners

1. Boom Design

There are several different types of boom.

- **Fence booms** have a rigid or semi-rigid material that floats upright in the water. They are difficult to handle and are often used for permanent installations around fuel transfer piers. Foam or hollow plastic chambers are used for flotation.
- **Curtain booms** have a flexible skirt that is held down by weights or a heavy bottom tension line. Flotation can consist of a variety of internal or external foams, self-inflating springs or wires and low pressure inflation.
- **External tension booms** are somewhat flexible with battens to keep them straight. Multiple bridle sets originate from the tension line and attach to the head and foot of the boom at intervals along its length. They are usually designed to contain oil on one side but can be rigged with two tension lines (one on each side) for reversing tidal currents. They usually rely on foam flotation however; inflatable flotation is sometimes used.
- **Shore sealing boom** use two cylindrical water ballast chambers on the bottom with one inflatable chamber on top so that when the tide goes down the boom will sit upright and seal against the shore.
- **Fire containment boom** uses a variety of materials that are fire resistant in order to withstand heat from *in situ* burning.

The fast-water containment boom of choice for protected waters usually consists of a strong curtain boom with no more than 6-inch draft and 4 to 6-inch diameter foam filled flotation. Strength is usually provided by an upper and lower tension member that also furnish stability in high currents. Long 6-inch diameter foam flotation logs are recommended for added resistance to bending in the current and for increased reserve buoyancy. A streamlined shape of the boom is important to reduce vortices that can initiate oil entrainment. To ensure a continuous smooth cylindrical shape, fabric should not be crimped or welded in between foam pieces. Interlocking channel connectors are recommended because they do not come apart if pins fail and are lighter than the ASTM "Z" connectors. Short 50-foot sections are recommended for cascade booming in currents greater than 2 knots in order to reduce drag and keep the boom section in shape. Multiple anchor attachment points along the boom allow for flexibility in deployment. Alternatives to this type of boom are discussed later in this report. Coastal and open bay protection will require larger flotation in waves. Tidal areas may benefit with shore seal boom.

2. Forces on a Boom and Rigging

The major force exerted on a boom is caused by the water drag on the skirt. Wave forces can increase the drag by a factor of two or three depending upon the wave height, period and loading dynamics. Wind force is less than current and waves but it is also a factor. Wind from one direction and current from the other can cause the boom to become unstable and lay over allowing oil to escape. Wind and water drag increase to the square of the relative velocity of the fluid passing by the boom. In high current situations, draft is sometimes increased by water piling up on the boom causing some submergence and increased drag forces.

a) Draft and Current Speed

Current forces increase dramatically with current velocity according to the formula[16] below:

$$F_c = 5.33 V_c^2 D \tag{2}$$

Where,
F_c = drag force due to current in pounds per linear foot of the boom profile to the current
V_c^2 = current velocity in knots
D = boom draft in feet

The effects of current velocity and boom draft on boom drag force can be seen in Figure 10.

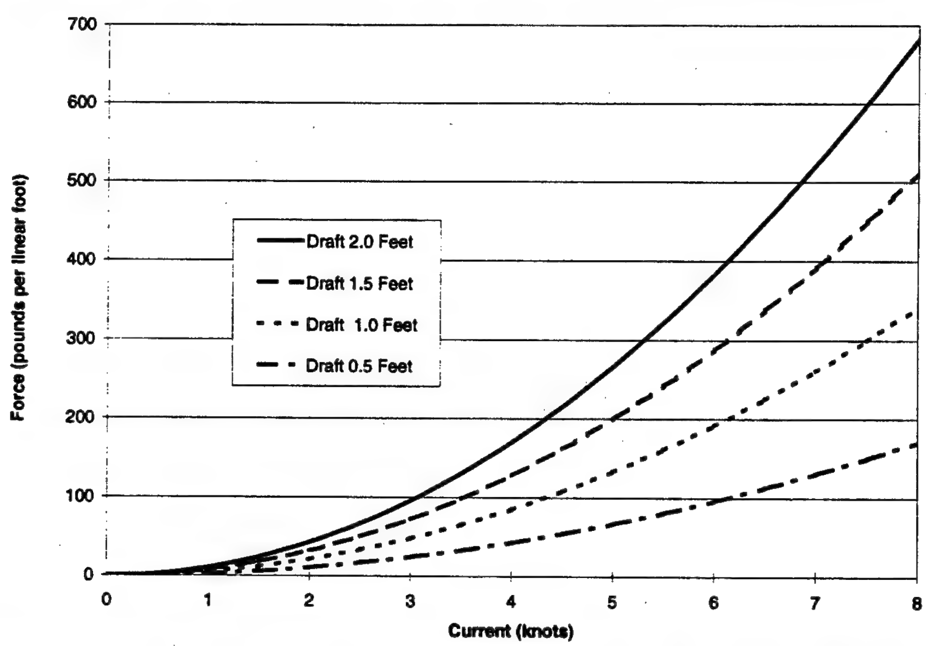


Figure 10. Drag Force on a Linear Foot of Boom as a Function of Current Speed and Draft

b) Mooring Angle Orientation

The additional forces exerted on a boom caused by the mooring angle are often neglected, but they become very large during diversion booming. A boom in a "U" configuration causes the mooring lines to be parallel with the current or at zero degrees. In this case, the total force on each mooring line is simply the force calculated from the boom profile to the current, obtained by using Equation 3, and then divided by two. As the mooring lines are pulled apart, the tension T in the mooring line increases, even if the same boom profile to the current is maintained as seen using Equation 4. Tension can be calculated based upon the angle of the mooring line to the current as shown

$$F = F_c P \tag{3}$$

below.

Where,
F = total force on the boom
F_c = drag force due to current in pounds per linear foot of the boom profile to the current, Equation 4
P = profile length of the boom to the current in feet

$$T = (F/2)(1/\cos\alpha) \tag{4}$$

Where,
T = tension in each mooring line
α = angle of the mooring line to the current

As the orientation of the boom relative to the current approaches 90 degrees, the tension on each mooring line increases dramatically. Tension in each mooring line is calculated for a 6-inch boom with a profile to the current of 100 feet as seen in Figure 11. Operators often underestimate the forces on a boom that is pulled tightly across a strong current that often results in equipment failure or mooring slippage.

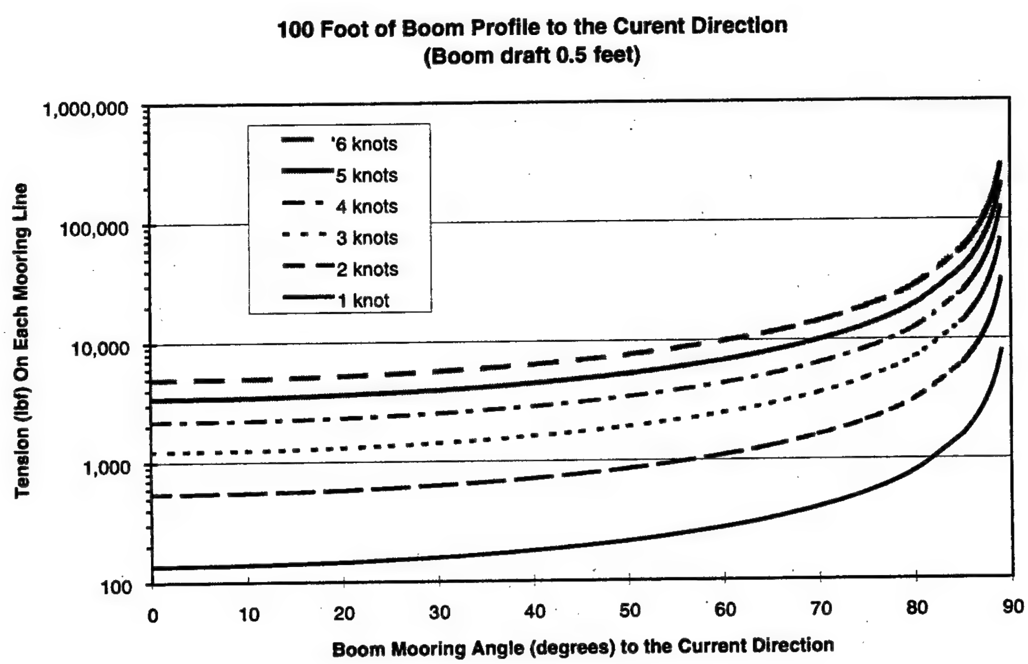


Figure 11. Boom Mooring Line Tension as a Function of Angle to the Current and Velocity

When using Equation 4 to calculate tension forces on a deflection boom, first calculate the force normal to the boom F_n such that $F_n = F \sin \theta$, where θ is the acute angle of the boom to the current. Tension T, is calculated using F_n in place of F in Equation 4 with α defined as 90 degrees minus the catenary angle of the boom. The catenary angle is measured between the slope of the boom deflected by the current and the imaginary line between the two boom mooring points. In the deflection boom case, α is the angle between the current normal force vector to the boom F_n and the mooring line. Using additional mooring attachment points along the boom will help keep the boom straight, distribute the load and reduce the forces on each mooring line.

3. Boom Strategies

Boom is used to contain, exclude and divert oil. Selection of the appropriate deployment strategy and equipment depends upon the type of waterbody, (river, bays or open water), velocity of the current, shape and type of shoreline, water depth, waves, wind, amount of oil and debris conditions.

- **Exclusion booming** is generally used when currents are less than one knot and waves are less than 1.5 feet. The boom can be placed directly across small bays, harbor entrances, river mouths and sensitive areas. Shore seal boom is useful for high tidal change areas when a shoreline is exposed at low tide. Exclusion booming can be used above one knot if the water current is oblique to the boom at the minimum angle to prevent oil entrainment.
- **Diversion booming** is used when currents are above one knot or when an area is too large to protect. Oil can be diverted away from a sensitive shoreline or into a natural collection along the shore. The boom can be deployed in a single long section or as multiple booms staggered across a river or harbor. As discussed earlier the minimum deflection angle must be maintained to prevent oil entrainment as shown in Figure 4. As the current increases, more acute angles are needed requiring longer length of boom. For example, 450 feet of boom is required to protect a 100-foot width channel in a three-knot current using a minimum of angle of 13 degrees.
- **Containment booming** is used on an open body of water, such as coastal regions, bays, large harbors and wide rivers. The boom is used to encircle the oil slick or trap it in a "U" or "V" configuration. When currents exceed 1 knot (1.6 knots for the V-shaped boom) these boom cannot be anchored because entrainment will occur. They must be towed or allowed to drift so that the relative current velocity does not exceed the critical oil escape velocity. Boom can sometimes be towed by two vessels in the direction of the current, however, maneuvering and station keeping is difficult moving downstream. Approximately one horsepower is required for every 20 pounds of drag.

a) Diversion to Calm Water Area

Diversion booming moves oil from fast flow in the center of the river to calm water in a protected inlet on the bank. If a suitable inlet is not available, a sump collection area can be dug out of the bank if heavy equipment is available. A calm water area allows the use of small conventional (low current) skimmers near shore where currents are below 0.5 kts. Two parallel booms are generally used to ensure oil is contained near shore. Boom is trenched into the bank to prevent oil loss at the shoreline. Visquine or another boom is used along the shore to keep the beach clean at the apex. Lightweight durable skimmers and power packs are recommended for easy transport and reliability. Typical skimmers include disk and drum skimmers to reduce water collection. Small weirs and vacuum (VAC) trucks, air conveyor systems or portable VAC units are also used but they collect more water than oil unless oil is thickened in the pocket before skimming or self adjusting floating skimmer heads are used. Several different floating suction heads or small weirs are available that are lightweight and can attach to a VAC unit, trash pump or peristaltic suction pump hose.

b) Cascading

(1) Narrow River

Cascade booming on a narrow river (less than 600-foot wide) can be accomplished without the use of anchors in the water. This speeds up the boom deployment process and allows for better control of each individual boom from shore.

(a) DOWCAR Environmental Technique

This technique has been perfected and taught by the DOWCAR Environment Management, Inc. for many years. It can be effective in currents up to 5 knots with a trained crew. They recommend using short 50-foot sections of 4 by 6 foam boom (4-inch flotation, 6-inch draft) when currents exceed 3 knots. This prevents excessive mooring, loading and boom shape distortion. They use 3/8-inch polypropylene mooring lines to prevent excessive drag in high current. Small boats and ferry line systems are used to move people and equipment across the river. Special mountain climbing equipment has been applied to make the rope handling easier. Ascenders are used in conjunction with pulleys to remove the slack from the mooring lines. Handled ascenders are also useful when hauling in a small diameter line by hand. Mountain climbing rope is recommended for the mooring lines when using ascenders to ensure a good grip. A loop of rope can also be effective to grab a line by wrapping it around the line and inside its own loop. This provides a good handhold that can be quickly slid up the line when slack is taken out.

Detailed procedures and graphics of the DOWCAR cascade technique are presented in Appendix I and Figures I-1 and I-2. Two upstream and two downstream lines are attached to each boom section to provide complete control from shore to position it properly. The completed installation is shown in Figure 12. A trained crew can boom a 200-foot wide river with a velocity of 3 knots in approximately 45 minutes.

Figure 12. Cascade Booming of a Narrow River

(2) Coastal and Wide River

Cascade booming is used in a similar mode along coastal areas and on wide rivers; however, anchors are needed to secure the boom offshore. This requires boats with high horsepower and appropriate anchors for the high drag forces involved. Setting boom in wide rivers and coastal rivers requires more time due to the logistics involved and the extra time needed for anchoring. Permanent anchors are recommended where sensitive areas have been identified for protection if anchor buoys will not interfere with vessel traffic. Diversion booms can also be used for directing the oil away from a sensitive area as seen in Appendix I, Figure I-3.

(a) Overlapping J-Shape Booms

In fast currents, the cascade booms form J-shape and oil will entrain under the boom at the apex. This apex forms at the downstream end. Oil loss can be contained by the next boom if they are overlapped a sufficient distance, as seen in Figure I-4.

c) Continuous Deflection

Whenever possible, continuous deflection booms are desirable because they can be deployed and retrieved more quickly than multiple cascade booms. This is generally possible in currents between one and two knots. Adaptations can be applied that allow continuous boom over long distances in higher speed currents.

(1) Narrow River

(a) Trans Mountain Pipeline Technique

The Trans Mountain Pipeline in British Columbia, Vancouver, Canada, has adopted and modified a version of the Canadian Petroleum Producers (CPP) deflection booming technique. The 20-inch diameter crude oil pipeline is 750 miles long and transits under 450 waterbodies. Many of the rivers have currents that exceed one knot. They have eight pre-staged equipment trailers with all the equipment required to respond to a release on these rivers and lakes. Jet drive boats are preferred for the shallow rocky rivers in which they operate. Helicopters are used to transport people and equipment from the trailers to the oil spill site in baskets.

Continuous sections of 6 by 6 (6-inch buoyancy and 6-inch skirt) foam boom are used for deflection and containment on fast flowing rivers. The long continuous boom would usually form a J-shape and loose oil at the apex. Distortion is reduced by attaching ropes to the boom at intervals and pulling the boom downstream to keep it straight. The shoreline ropes attach to the boom with special bridles. The ends of the bridles are separated by a light pipe with snap hooks on each end that attach to rings on the top and bottom of the boom. The pipe keeps the boom from collapsing when the lines are pulled to shore. This process puts a large force on the boom anchor line upstream, so 3/8-inch cable is used to take this high tensile load to the anchor. A tow paravane is attached to the leading edge of the boom for added buoyancy. Various anchor techniques are used such as trees, bridge piers, cable ferry systems and anchors. A cable ferry system allows for changes in the deflection angle to compensate for changing currents and to avoid large debris. They use shallow draft self-adjusting weir or disk skimmers in the apex of the boom. Suction trash pumps remove oil collected by the skimmer. Several different configuration of this technique are shown in Appendix J, Figure J-1. A 200-foot wide fast-water river can be protected in approximately 30 minutes using this technique. A second layout of the boom system shown can be setup downstream on the opposite bank if required for wider rivers. This technique can also be used for near shore containment deflection in coastal applications.

(b) External Tension Line Boom

External tension line boom can be very effective across narrow rivers in high currents. The external tension line is passed to the other shore over a bridge or carried across using a small boat. The line is tightened between trees, large rocks or anchors. The line is positioned downstream at the required deflection angle. Pulleys or ratchet devices are used to tighten the line. The boom is then deployed from the upstream side. Attachment bridles are snapped onto rings that glide over the tension line. An outhaul and inhaul line is attached to the lead end of the boom. The outhaul line is passed across the river and it is used to pull the boom to the opposite bank downstream. The current assists in moving the boom along the tension line and across the river. The external tension line functions like a shower curtain rod. A second external-tension line can be deployed on the opposite side of the boom with another set of bridles if reversing tidal currents are present. This would require moving the skimmer during each tidal change or having a second skimmer on the opposite bank. The upstream external tension line can also serve to prevent debris from entering the boom skimming apex area. Another parallel upstream external tension line (one above the water and one below) can be used with a net attached between them. This net will catch debris before it hits the boom and propagates down into the oil collection pocket.

(2) Coastal and Wide River

(a) Multiple Anchors on a Continuous Boom

A long continuous section of boom can be used for wide-river, coastal, and open-water diversion scenarios. This type of deployment requires multiple anchors along the boom to keep it from forming a "U" or J-shape in high currents. The evolution is time consuming and requires expert seamanship to properly position the anchors and boom. Large debris can take out the entire boom section. If one anchor is out of position or dislodges, oil will entrain under the boom.

(b) Boom Deflectors on a Multiple Section

Boom deflectors were first developed and tested during six field trials in 1975 and 1976. They operate by providing a floating deflector arm off the downstream side of the boom at selected intervals. The hydrodynamic force of water flowing behind the boom hits the arm and pushes the boom into the current. The push on the deflector corresponds

to the speed of the current and the angle set on the deflector. The boom is deflected up to a maximum of 20 degrees to the current. Faster currents require that a smaller angle be set on the deflector.

The original prototype design was constructed of wood and was placed over the boom and attached to it. This design was difficult to work with and tended to crimp the boom causing vortices and entrainment. The deflectors had 12-foot long bodies with 12-foot deflector arms. They were placed over the boom at 20-foot intervals and tended to form a zigzag pattern at greater angles to the current.[17] The next generation of deflectors has been recently developed by Envirotech Nisku Inc. of Alberta, Canada. US and Canadian patents are pending approval. These deflectors are shown during a deployment in Figure 13.

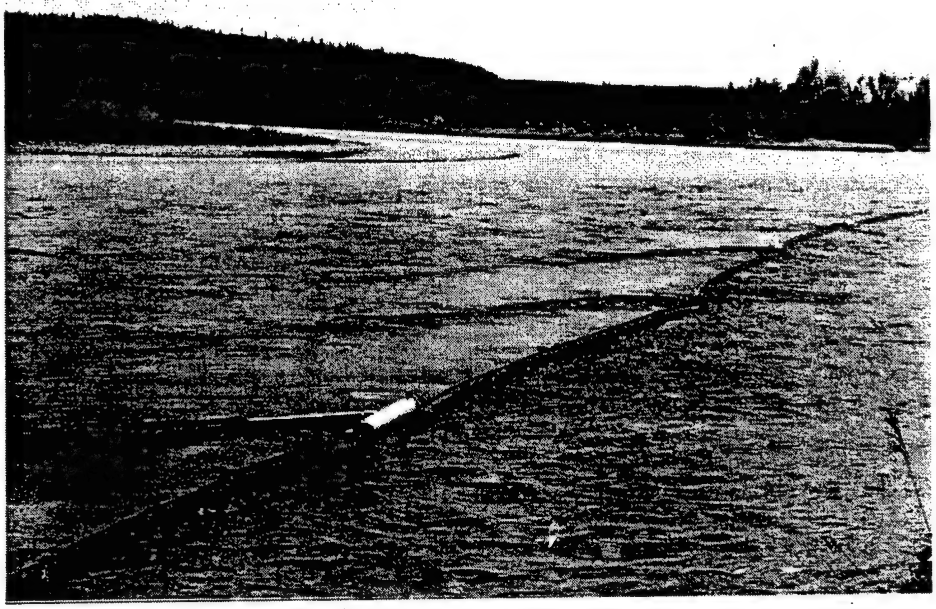


Figure 13. Boom Deflectors in High Current

The Envirotech deflectors are streamlined aluminum boom sections 16 inches high and about seven feet long that attach in between boom sections using ASTM connectors. A 12-inch high by 5-foot long rigid and buoyant deflector arm attaches to one of two hinges on the body section so that it is reversible and can deflect boom in either direction. The deflector hinge allows water passage between the deflector arm and the body to reduce turbulence near the boom. Short 50-foot sections of boom are recommended so that the deflectors are effective at keeping the boom straight at the desired deflection angle. Only one lead anchor point is required upstream. No shore line ropes or additional anchors are needed to keep the boom in shape and angled into the current. The upstream leading end of the boom at the anchor attachment point does not require a deflector however a paravane with added buoyancy is recommended in strong currents. The deflectors are deployed fastened in the closed position. After the boom is deployed and attached to the anchor, the deflector closest to the anchor point is set and locked in place. Each deflector is then set at the same angle downstream. The deflector arm is set at the desired angle to get the amount of boom deflection required. The arms are easily adjustable from a small boat. The boom is observed and adjustment to any deflectors can be made as required. The boom will then be angled to shore for skimming operations or away from sensitive areas for exclusion deflection. For skimming applications, a near-shore boom and skimmer are added. A rope is attached to the last section of boom to keep the skimmer in position. A diagram showing the boom-deflector system used with a skimmer is shown in Appendix K, Figure K-1.

The benefits of boom deflectors are faster deployment times, fewer people required for deployment, and no ropes to shore that may snag debris or divert oil. If a straighter and smoother boom angle is obtained by using deflectors in lieu of multiple anchors, then entrainment caused by anchor point discontinuities along the boom and associated vortices will be eliminated. This system is very useful in wide rivers and along coastal regions, where deflection away from sensitive areas is required and using multiple anchors or cascade booming is either too difficult or too time consuming. The deflectors also show promise to keep two booms at desired deflection angles for wide sweep

systems when using two tow vessels. A large advancing V-shape boom deployment can be maintained with the use of boom deflectors for the purposes of concentrating oil into rows for a trailing skimmer. The deflectors would eliminate the use of many long cross bridles normally required in such an operation along with the rigging time and bottom snag hazard that the bridles usually pose. Maneuvering the sweep system would be easier without multiple cross bridles and the potential for debris snags would be greatly reduced. This oil concentrating system could also be deployed from bridge piers in fast moving currents.

d) Current Rudder (Vessel Passage Allowed)

A current rudder has been recently developed by Blomberg Offshore AB of Vastra Frolunda, Sweden. Patents are pending approval. The current rudder consists of a frame that supports one to four paravanes that are fixed parallel to each other and perpendicular to the frame. A prototype system made of aluminum with streamlined paravanes is shown in Figure 14. The top of the frame and paravanes contains flotation material that allows the rudder to float upright with very little freeboard. The current rudder uses hydrodynamic forces of a passing current to pull a boom into a current with control lines attached to a capstan on the shore. It can also be used to deploy a sweep system from the side of an advancing ship without the use of cumbersome outriggers. More paravanes are required in slower currents or when greater pulling power is required for longer or deeper draft boom. The paravanes can be wing shaped as shown or made more simply with plates and a fixed angle on the trailing edge to reduce cost.

Figure 14. Current Rudder Paravanes

Two control lines are attached to the inboard and outboard ends of the frame with bridles that connect to the top and bottom of the frame. Control lines are run upstream a distance approximately equal to the width of the river to be boomed. They wrap around a portable capstan mounted on a plate that is secured to the ground with stakes and anchors. The boom is attached to the inboard side of the frame with another bridle. The current rudder is positioned in the water so that the paravanes are parallel to the current or angled into the shore. Boom is positioned along the shore down river. The length of boom is selected knowing the width of the coverage area and minimum deflection angle desired. Shoreline ropes are sometimes required in strong currents with long sections of boom to keep the boom from deforming. They are attached to the boom with bridles at required intervals. The downstream end of the boom is moored to shore or to an inline skimmer as desired. Boom is then deployed across the river by changing the angle of attack of the paravanes with the capstan as shown in Appendix L, Figure L-1. Only a few degrees of angle toward the opposite bank are required to move the boom across the river. An excessive angle can cause undesirable turbulence at the trailing edge of the paravanes. Shoreline ropes are pulled downstream and secured to anchors to keep the boom in a proper shape. When vessel traffic needs to pass or large debris floats downstream, the boom is quickly retrieved to shore by one person controlling the capstan and changing the paravane angle of attack to point toward the near shore. After vessel passage, the boom is deployed back out into the channel in the opposite manner. It is likely that this deployment could also be accomplished with boom deflectors described in the previous section without the use of shoreline ropes.

e) Chevron Diversion to Both Sides

Chevron booming is used when deflection to both sides of a small bay, channel or river is desirable. It is effective in currents from 1 to 2 knots. Currents above 2 knots will tend to cause deformation of the boom and result in oil entrainment. This can be reduced to some extent by double booming behind the first system. The two chevron strategies described below are shown in Figure 15.

(1) Open Chevron (Vessel Passage Allowed)

An open chevron uses two mid-channel anchors separated by a distance that allows vessels to pass between them safely. Each boom forms a single leg to the opposite shore. The booms can overlap to some extent to prevent oil from getting by. This operation takes more time to deploy; however, it is recommended where vessel passage is desired.

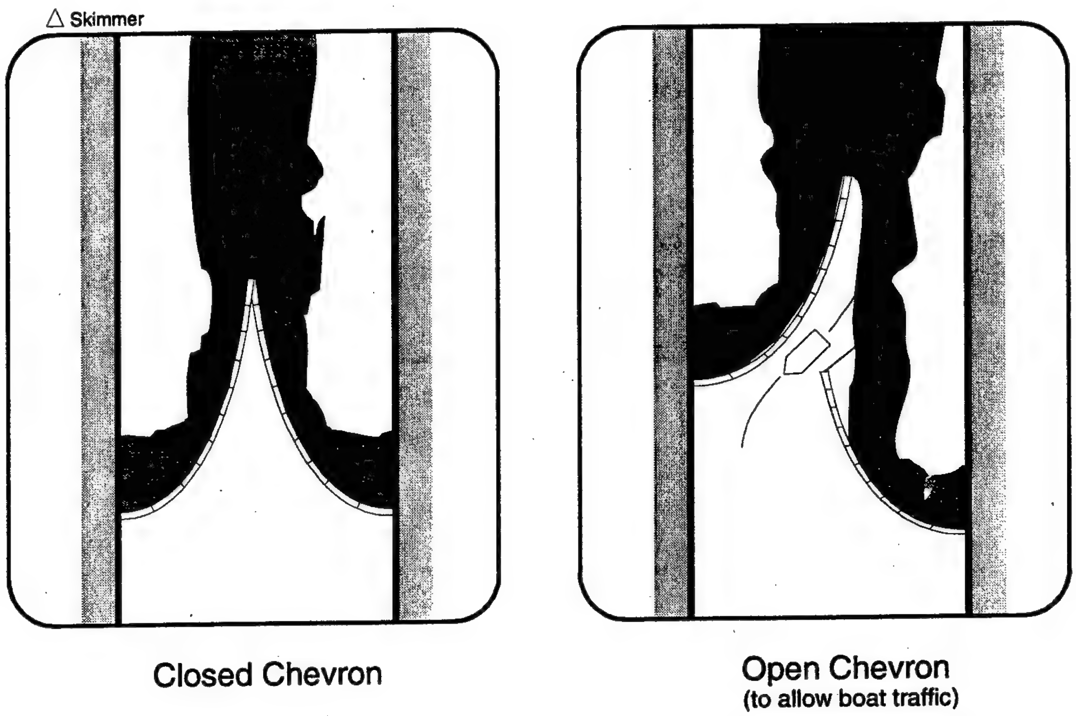


Figure 15. Chevron Booming Strategies

(2) Closed Chevron

The standard closed chevron uses one anchor point in the center of a channel. Two sections of boom are attached to the mid-cannel anchor. They trail downstream to opposite banks, where they are secured to shore anchor points. The shape of the boom is controlled by tension on the boom. Additional anchors along the boom are usually not used. The desired angle is obtained by adjusting the length of boom. This method is most effective when permanent mooring points are in place and the boom can be deployed very quickly. The Piscataqua River Cooperative in Portsmouth, New Hampshire uses this strategy with 5,000 feet of boom to protect Little Bay during a high current flood tide.

f) Double Booming

Double booming refers to setting up a second deflection boom behind the first one. This is done to contain any oil that may entrain under the first boom in high currents. It is routinely done behind the oil collection pocket near shore. It can also be done behind the entire length of boom, Figure 16. Studies have shown that double booming also improves performance in high currents by providing a quiescent zone between the booms. Entrainment is further reduced with by a plate or foil below the booms that causes a recirculation pattern between them.[18] Oil will tend to stay between the booms because the relative velocity of water going by the oil is reduced by the first boom.

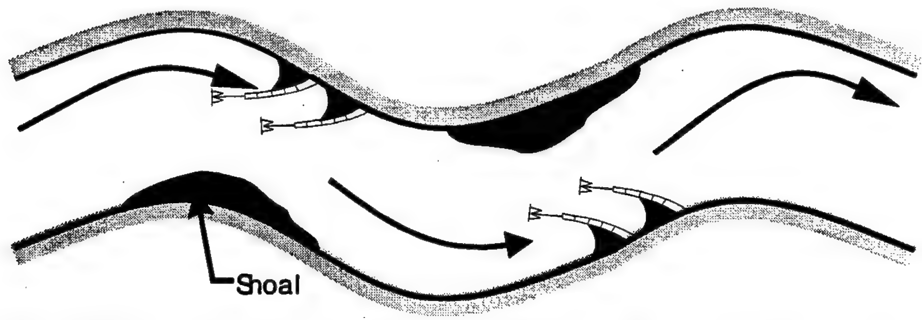


Figure 16. Double Booming Strategy and Recommended Boom Placement on Winding Rivers

A study was also conducted in Canada to evaluate a Horizontal Oil Boom consisting of two inflatable floats connected together by net and non-woven polyester fabric.[19] The Viledon fabric permits water to flow but not oil. The 30 by 30-millimeter mesh net comprised the first third and the non-woven fabric comprised the final two thirds of the submerged portion between the two floats. The system was placed across a fast flowing river at a deflection angle of 36 degrees. Personal communication with an observer of the field tests stated that the fabric quickly clogged with oil that prevented water passage causing the floats to collapse upon each other.[20]

g) *Encircle and Divert*

In wide rivers and coastal areas boom can also be used to encircle the large oil patches while moving with the current. Then the oil is slowly diverted (<1 knot relative to the surface current) to a low current eddy or inlet for skimming. A patch of oil can be encircled by one boat by using a sea anchor to resist boom movement while the boat circles the oil as seen in Figure 17.

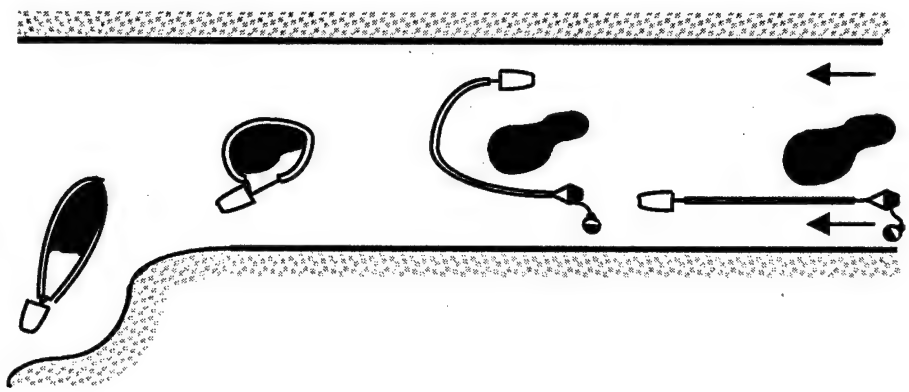


Figure 17. Procedure Used by one Boat to Capture Oil and Divert it to Slower Waters

4. Boom Deployment Techniques and Tactics

a) *Seamanship and Safety*

Safety is very important when working with equipment on fast moving water. The high forces exerted on boom and boats make it much more difficult to maneuver and operate safely. Less time is available to react to conditions in high-speed currents. The most experienced boat operators are required for operations in high currents. Knowledge and awareness of the current, wind and operating area are essential. Proper boat selection is also very important. Vessel configurations that allow for boom and equipment to be easily pulled overboard and retrieved through a bow or stern ramp that can be lowered to the water's edge are very useful. Boat stability, working area, visibility, deck arrangement, freeboard, seakeeping, propulsion type and horsepower are important factors. Adequate horsepower is very often underestimated for towing boom in fast water. Boom drag and mooring angle considerations should be used to determine the bollard pull required for the scenario and operating area. Horsepower required for that pulling capacity should be selected with a margin of safety with assistance from the boat or engine manufacturer.

Knowledge and experience towing boom is essential to ensure it is done properly and safely. It should ideally be tied off to a towing bit forward of the rudder or outboard motor to gain good vessel turning control. If that is not possible, the boom towing line should be attached to a clip that is allowed to slide across a line tied between the two

outermost cleats on the stern of the vessel. If boom cannot be towed against the current, drag can be reduced by decreasing the projected area of the boom to the current.

All personnel working at a spill site must be in life jackets that are zipped up. Awareness of lines and forces on them is critical to prevent injuries. Personnel should avoid stepping over lines or standing behind lines under tension.

b) Tie up the Skirt

Another technique used to position and anchor boom in high currents its to tie the boom skirt up to the flotation with line. This will drastically reduce drag on the boom while the boom is deployed. Once the boom is in position, the lines are cut starting from the shore side collection pocket and working upstream. If it appears that the boom is losing the desired shape below the minimum entrainment angle then several options are available. Additional anchors or shoreline ropes can be attached to the boom or the boom can be left with the skirt tied up away from the pocket. There will usually be enough draft on the boom in this region when deflecting oil at steep angles.

c) Pre-staged Equipment

Prior planning cannot be overemphasized for protecting sensitive areas. Fast current areas often require pre-staged equipment in order to ensure it is deployed fast enough to protect those sensitive areas. There are many options available for pre-staged equipment. The most effective setup is to load boom on reels or deployment racks adjacent to the shore where it can be pulled out into the water by a vessel. If this is not possible then the next option is to have barges and vessels loaded with equipment at a nearby facility. This is very desirable and provides more flexibility in getting to different destinations. Other options include boats and equipment on trailers staged at location near the sensitive areas. Boom and other equipment can also be placed in lightweight containers that can be lifted by helicopter as a sling load or placed inside a large fixed wing aircraft for quick transit to the area required. Periodic preventive and corrective maintenance is required to ensure that pre-staged equipment is in good operating condition when it is needed. This is one of the most neglected areas of a response system.

The availability of trained personnel to respond quickly is also equally important. The highest level of response is with boats and facilities manned 24 hours a day, seven days a week with an initial response crew. Other stages of readiness include personnel time that can be reached 24 hours a day by beepers and telephones and can respond within a certain minimum response. Periodic practice and experience actually deploying and using the equipment in fast currents is the most important aspect to ensure a successful response. Tabletop exercises alone are not adequate to prepare for oil spills in fast currents. The training and response times required by the US Coast Guard response plans and OSRO guidelines are minimum requirements and they are not written to address response in high-speed currents. To be effective in fast water, these requirements must be exceeded in every respect.

d) Pre-Deployed Boom

The most important aspect to reducing the impact of an oil spill is the quick containment of the oil close to the spill site. This can be most effectively accomplished when boom is deployed before the spill occurs and is used in high-risk situations such as refueling operations and oil transfers in the water. It can also be used to protect sensitive areas when enough time is not available to respond. This can be accomplished by permanent installations, seasonal installations and event deployment of boom or other containment devices. Event deployment is usually the most expensive due to the time and personnel involved each time a potential high-risk spill event occurs. Permanent booms are installed at refueling piers and oil transfer terminals that have a high risk or history of spills. This can be accomplished where the predominant current and wind conditions are well known and predictable. Seasonal deployment of equipment is associated with seasonal high risks of oil spills. Pre-deployed boom should be positioned to contain oil in the worst case scenario during the deployment period. For example, the deflection angle should be set at the minimum angle required for the highest current during that period.

The Alaska Clean Seas cooperative in Prudhoe Bay, Alaska has a very proactive strategy for the protection of many high current streams and rivers along their pipeline route. They have decided, due to fast currents and the remote location of these waterbodies, that the most effective strategy is to deploy deflection boom for the entire summer season after the ice has melted. They deploy thousands of feet of boom in a diversionary mode on many of the major and remote rivers in their area of operations each year and the booms are left in place until the fall. This can be done in their operating area because these rivers and streams are not traveled by vessels. Their objectives are to prevent sensitive areas from being contaminated and to keep oil from entering the bay if a spill occurs.

5. Specialized Fast Water Booms

Booms used on fast currents are usually specialized to some extent to be more effective and resistant to damage in this very tough environment. The fast water boom must be stronger, more stable, have sufficient reserve buoyancy and more anchor points than most low current booms. The face of the boom that contacts oil should be streamlined to prevent turbulence and vortices that will entrain oil under the boom.

a) Fast Water Boom 6" X 6"

The recommended boom for oil deflection in waters with less than 1.5-foot waves is a 6-inch diameter foam-filled flotation and no more than a 6-inch draft. This curtain boom should have a top and bottom tension member and be capable of withstanding the high tensile load in the current and configuration that it will be used. Long cylindrical high density but flexible closed cell foam logs are desired to resist bending in the current. The boom fabric should not be welded in-between foam floats to present an even cylindrical profile to the passing water and oil. Fifty-foot section lengths are recommended for currents above 2 knots when cascade booming is used. This reduces the forces on each section and allows the boom to maintain a straighter shape.

b) Drag Reduction Boom

Techniques have been developed to reduce the drag of booms in high currents where more than 6-inch draft is required due to waves, greater stability requirements or higher oil volume.

(1) Holes in the Skirt

Some manufacturers offer high current boom that have holes cut in the bottom portion of the fabric skirt to reduce drag. No tests under controlled conditions of this boom type were found in the literature. Its potential benefit of greater stability in strong currents or high speed towing is diminished by the potential that the holes may create turbulence that can entrain oil prematurely. Drag reduction by holes that cover less than 50 percent off the surface area is limited. The amount of boom skirt available for containment is often reduced to a few inches that will allow premature oil drainage. The holes will weaken the fabric and be a potential source of structural failure. This type of boom appears to have more marketing hype than actual benefits for booming in high currents.

(2) Net Skirt

The use of nets on the bottom portion of a boom skirt is also used to reduce drag in high currents or fast towing situations. This technique will reduce drag more efficiently than holes cut in fabric because the percent of open area is greater. Structural strength is maintained with the proper net material and mesh size. The net has the potential to cause turbulence and oil entrainment but less than holes cut in the fabric. Tests were conducted at OHMSETT with a short section of "feather net" attached to the bottom of a 54-inch offshore boom. Its function was more as a shock absorber between the inflation chamber and bottom tension member than for drag reduction. It was, however, responsible for increasing the speed before first oil loss occurred by approximately 10 percent when towed in a "U" configuration and it contained oil at speed of 1.2 knots.[21] Booms consisting of all net with a fine mesh have been used to collect very viscous oil and tar balls similar to bottom trawl fish nets, but on the surface. Conventional deflection boom is used to funnel the oil into the net. They may be effective in high currents but data is not available to substantiate this. Nets are a source of oil retention and so they should be cleaned thoroughly after use. They can be coated in plastic to prevent oil from soaking into the fibers and to make decontamination easier.

c) V-Shaped Boom

Nets can be used to keep deflection boom in a V-shape. The net attaches to the foot of the boom and holds it in shape while the water pushes it open and attempts to distort its shape. The net has a smaller mesh size at the apex, as seen in Figure 18. This allows more water to exit through the net and under the boom forward of the apex, thus, reducing oil entrainment in the collection pocket. There are two manufacturers of this type of product but both are geared more to offshore wave environments. They are Oil Stop Inc. in Harvey, Louisiana, and AllMartime AS in Bergin, Norway. Tests at OHMSETT have shown the boom can contain and recover oil with a weir skimmer in the apex at speed of 1.6 knots.[21] The smaller V-shape pocket is more efficient at thickening the oil than the much wider U-shape that forms without the net. The thicker layer of oil allows for more efficient skimmer operation. The apex end section of the Oil Stop Inc. Fast Sweep™ boom design can be removed for attachment of an inline skimmer. This configuration was shown to be more effective in currents up to 3 knots when used with several different types of inline skimmers during evaluations at OHMSETT as part of the USCG High-Speed Skimmer acquisition. This offshore boom is limited because it starts to submerge at currents above 3 knots due to the downward forces of the

water that is piled up in the apex of the boom. It shows potential to be effective with inline skimmers at higher speeds by increasing buoyancy at the apex or reducing draft of the boom. The attachment method to the inline skimmer is also important to a successful operation. A short straight channel of shallow draft boom was used in-between the V-shaped boom and the inline skimmer. This allowed more water to escape and allowed for a more effective flow of oil into the skimmer that improved efficiency of the system.

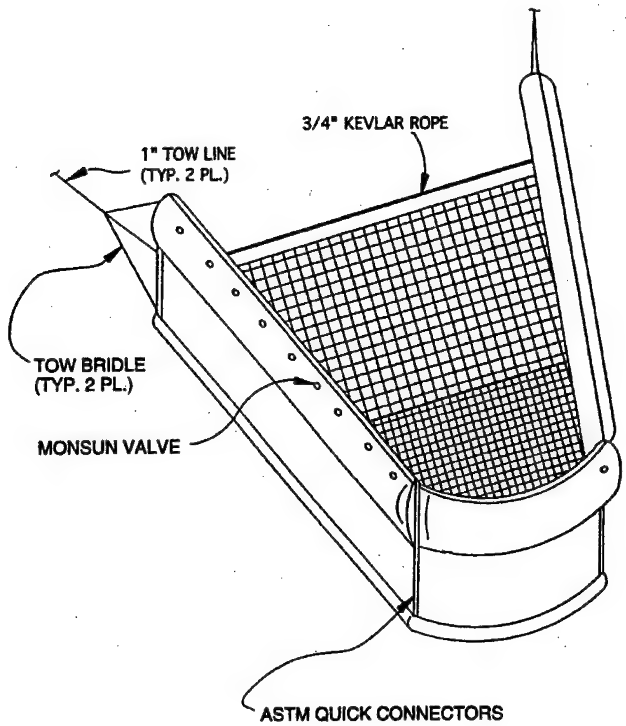


Figure 18. Fast Sweep™ V-Shaped Boom

d) Inclined Plane Boom

The University of New Hampshire (UNH) has been developing a submergence plane boom with funding from the USCG and Minerals Management Service (MMS) during the past few years. Patents are pending approval. The device forces oil down a reinforced fabric inclined plane by the current or forward motion of the Rapid Current Containment Boom. The oil is separated from the water by a fabric plane that is below and aft of the bottom of the incline and parallel to the surface. This sheet extends to the bottom of the U-shaped collection boom. Holes have been cut in the fabric in the apex area to let water out and reduce the backpressure to ensure a free flow of water into the collection area. This quiescent zone shields the captured oil from the higher water velocities below the bottom of the system, thus allowing oil collection and containment as speeds up to 2.5 knots as demonstrated in the UNH circulating water channel and OHMSETT tow tank tests.[22] The failure mode was submergence of the aft end of the containment boom. This performance could be improved by providing increased buoyancy to the boom. The shape of the boom should be modified into more of a V-shape. This should improve oil thickening in the apex and allow more flexibility to improve the arrangement of exit holes in the bottom fabric. In the present design, holes must extend back to the apex of the boom in order to get the exit volume of water required. A V-shape will allow for exit holes to be positioned forward of the apex and provide a more protected area for the oil to collect. A photograph of a prototype Rapid Current Containment Boom test at OHMSETT is shown in Figure 19.

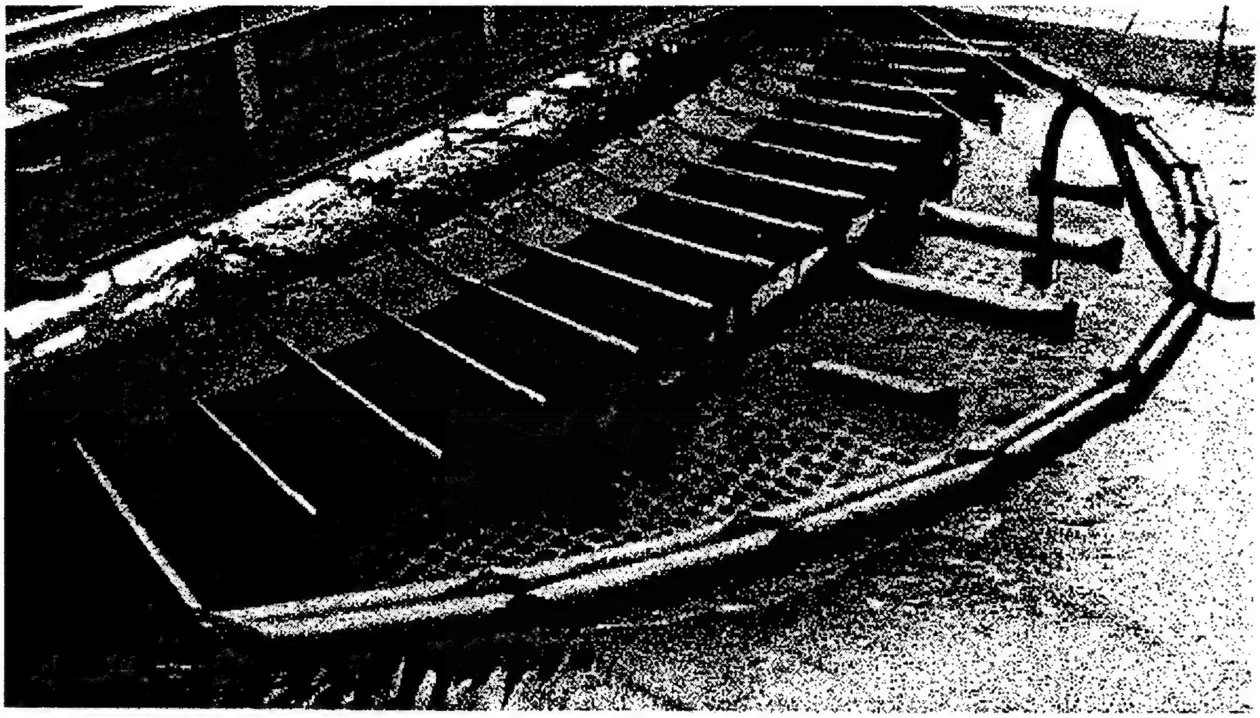


Figure 19. UNH Rapid Current Containment Boom

e) Shell High Current Boom

The Shell High Current Boom is a rigid modular aluminum structure designed to contain oil by providing a quiescent zone using perforated plates to separate the oil from the water. The oil then migrates down the incline and apex near shore where it is removed by skimmers or a suction hose. It is designed to be attached to other 8-foot long by 4-foot wide modules in order to bridge across a river at an angle. It can also be used on a vessel of opportunity attached at the side. Good performance was achieved in high currents by placing a baffle upstream of a conventional flat plate boom. The baffle is an inclined perforated plate that creates a flow-sheltered area where the oil layer thickens as seen in Figure 20.

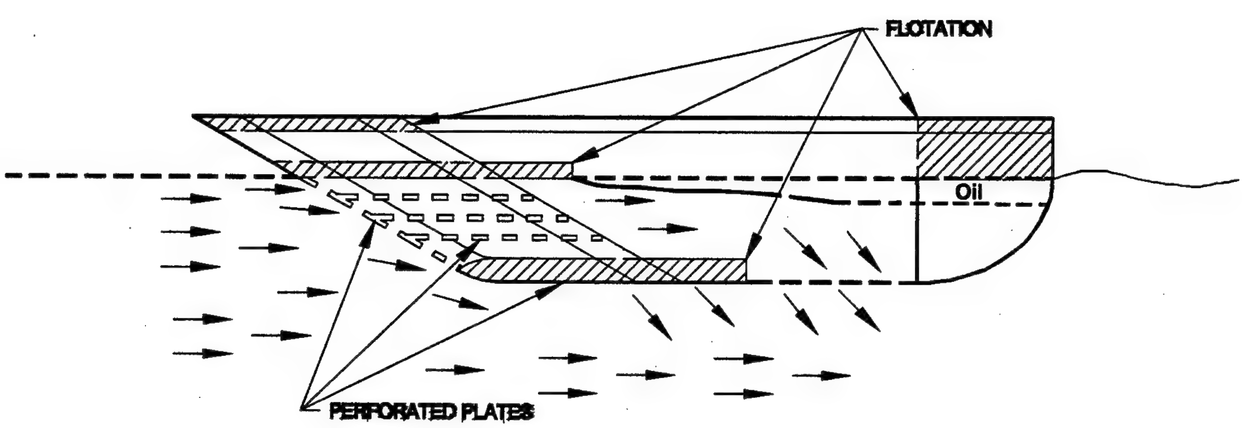


Figure 20. Shell High Current Boom (Aluminum Structure)

The boom was tested at OHMSETT at 90 and 45 degrees to the current in the late 1970s.[23] It contained 85 percent of No. 2 and No. 4 oil in a 3-knot current with the boom 45 degrees to the current. Increasing the speed to 3.5 knots reduced containment down to 70 percent. It contained 80 percent of oil perpendicular to a 2.5-knot current. Six to eight inch waves had little effect of the system performance.

This system showed promising performance in calm water conditions. The rigid structure makes it somewhat difficult to transport and deploy. The wave following characteristics of this boom structure are poor in wave conditions found offshore and in open bays.

f) Boom Sock

The boom sock is a covered boom towed alongside a tending vessel. The boom collects oil in the same way as conventional boom except that the cover dampens out small waves and reduces wave reflections. The boom is 4.5 feet deep to allow for large volume of oil. It is 25 feet wide and 43 feet long and forms a U-shape when towed by a leading floating frame. The oil is collected through multiple suction points along the top of the cover. The first half of the sock has a fabric bottom. The apex is open underneath allowing water to exit.
During tests at OHMSETT, it could collect oil at speeds up to 1.8 knots with a throughput efficiency 98 percent and recovery efficiency of 70 percent.[24]

D. Alternate Containment or Diversion Methods

There are a number of other methods used to control oil on the surface of the water. Many of these require a large amount of power to move the water and oil in the desired direction. These methods have limits due the physics involved, logistics and power requirements. They usually are more expensive and complex than boom systems, but each has a particular benefit over conventional boom that can be exploited for fast water applications.

1. Pneumatic Boom

Pneumatic boom consists of a pipe or hose submerged below the surface of the water that is supplied with compressed air. The air escapes through small holes in the pipe and creates a large number of fine bubbles. The bubbles rise to the surface due to buoyancy, moving water with them and creating a vertical current. The vertical current splits into two currents on the surface moving away from the boom in opposite directions. This surface current will block the approach of oil on the surface of the water as seen in Figure 21.

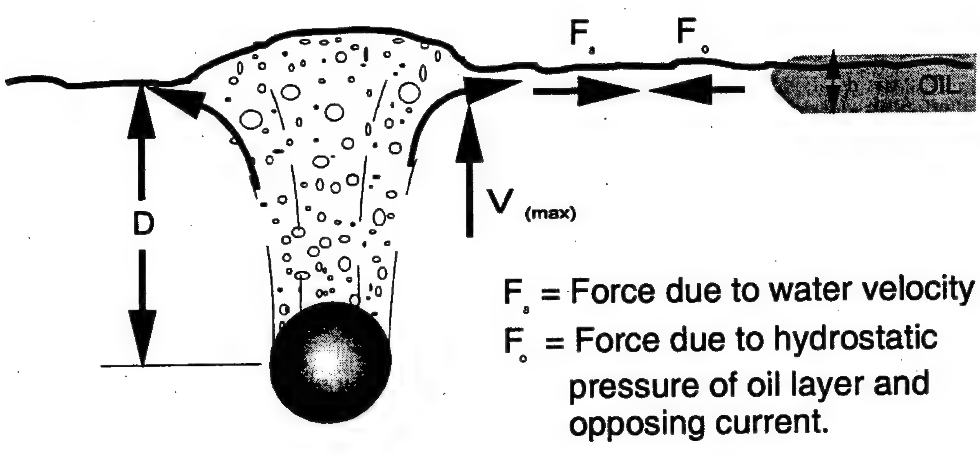


Figure 21. Balance of Forces between a Bubble Plume and Oil Layer[25]

The maximum surface water velocity, $V_{(max)}$ generated by rising bubbles is related to the air flow rate per unit length of discharge line. In waves, the oil must be kept some distance from the boom to keep oil from being carried across the boom by orbital motions in the wave field. A current of 1 knot can be generated with a modest flow rate of two standard cubic feet per minute per foot of discharge pipe (SCFM/FT). This will require 30 hp/ft in 12 feet of water.[25] Air flow rates above 5 SCFM/FT are not practical because considerably larger and costlier blowers providing approximately 75 hp/ft are required to obtain even marginally greater water velocities.[25]. This can be seen in Figure 22, where a 1.3-knot current is created with five SCFM/FT.

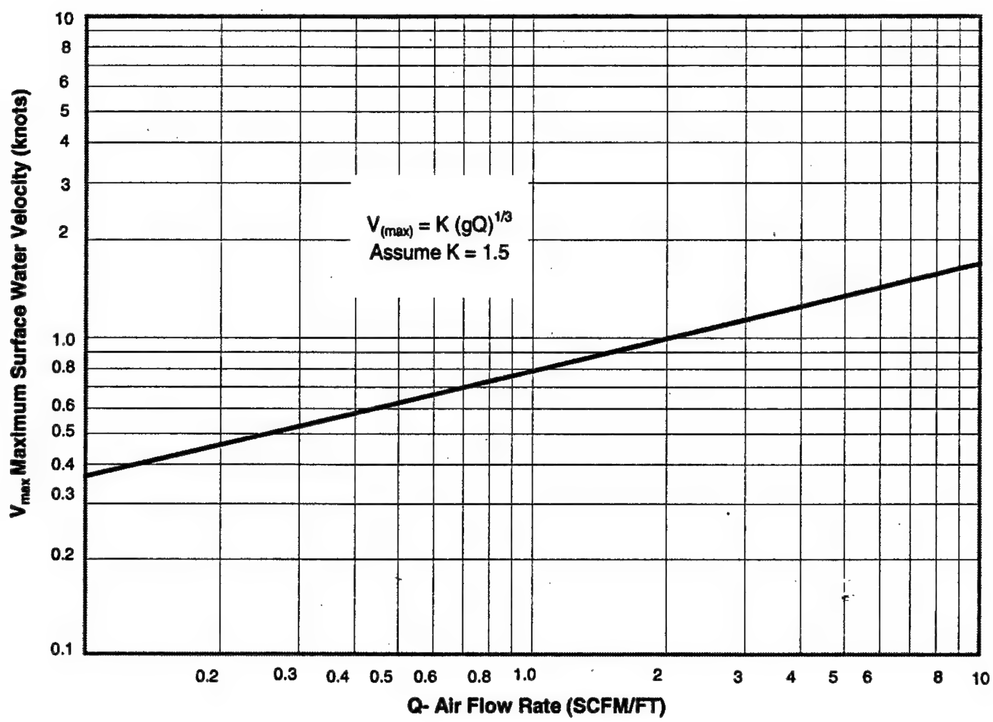


Figure 22. Effect of Airflow Rate on the Maximum Surface Velocity[25]

The current produced by a pneumatic boom can be used in a diversionary mode to deflect oil away from sensitive areas or into a containment area. This concept was evaluated in several different configurations at eleven river sites throughout Canada. The air diverter system was determined to be a viable alternative concept to conventional mechanical deflection systems. The stagnation line allowed most types of floating debris such as pack ice and logs to pass through while maintaining its oil deflection capabilities. A diverter system set at 30 degrees to the current was effective in diverting oil in a four knot current.[26] Other tests, however, had difficulty due to displacement of pipes by high currents, blockage of holes in the pipe by silt and uneven air flow due to the pipe being placed with holes out to the side. It was not effective under solid ice.

This type of system is best suited for permanent installations around vessel traffic areas or fuel transfer piers for currents less than 2 knots. In this way, it can be ready whenever needed. Regular maintenance is required to keep the air compressor or blower operational and the pipes free from silt. Turbulence in the water column can cause oil entrainment thus reducing the effectiveness of the system. Air pipes on land and near the surface of the water will have to be insulated and/or heated for applications in winter icing conditions. Air bubblers have the added advantage of keeping ice from forming above them if they are kept running continuously because the warmer water from below is circulated to the surface by the vertical current.

2. Water Jet

Water jets can induce surface currents and thereby control the flow and direction of oil.

a) *Horizontal Water Jet*

High-pressure water that is forced through nozzles suspended about one foot above the surface can contain oil. They can be located perpendicular to the water surface or depressed about 15 degrees. Tests conducted showed that both horizontal and depressed spray water jets can be contain oil in currents up to 1.2 knots.[27] The depressed jet, however, required 27 percent less pressure but turbulence could occur if pressure exceeds 1,138 PSI. The water spray system is more efficient than the pneumatic boom system because it creates a surface current in only one direction. The water jet system requires much less power to create the same surface current than pneumatic boom, in some cases about ten percent of the power required by the pneumatic boom.[28] Some water jets are designed to be kept in place as a deflection area or oil can be maneuvered into place by using opposing water jets. Control of the water pressure to the opposite side jets can be used to move the arms into position.

Tests were also conducted to evaluate flexible manifolds and pipe connections supported above the water by catamaran floats. The nozzles were aligned foreword and inward on the water's surface to drive the oil to a central collection area while moving forward. The water spraying arrangement was designed for 5 knots at a deflection angle of 30 degrees to the current, but field tests were conducted at 3.5 knots with an estimate of 0-10 percent losses.[29]

Horizontal water jets can be effective to deflect oil in currents up to 2 knots in a diversion mode. They may be more effective in permanent installations than deployable free floating systems. This method may be effective keeping oil out under from piers and low-lying bridges if tidal height fluctuations are less than one foot. They may be most effective as diversion systems suspended in front of high-speed skimmers to concentrate oil into the skimmer and increase its sweep width. There have also been discussions in the literature to use water jets for in situ burning barriers because they can contain oil and induce wind to assist in the burning process. Horizontal water jets require maintenance to ensue the jets do not clog or ice up. The high-pressure pump and power pack must also be maintained. Horsepower requirements are approximately 3 hp/foot of discharge hose with nozzles. Significant logistics are required to transport and deploy floats, hose and power pack/pump in order to use horizontal water jets.

b) *Plunging Water Jet*

A plunging water jet is a high-velocity (35 ft/sec), non-spraying stream of water directed vertically downward into the water. Large and small air bubbles are entrained into the water column. As the air rises to the surface, it creates a vertical current that spreads out in a radial direction on the surface pushing oil away. The surface of the water also is higher due to the water entrained by the large bubbles. Small bubbles rise more slowly and continue to contribute to the vertical and radial surface current. Plunging water jets can produce a current that lasts up to one minute. Tests have demonstrated that plunging water jets can be effective as oil deflection devices in front of a high speed skimmer at speeds up to 6 knots.[30] The jets were most effective when suspended 1.5 to 3 feet above the water. Plunging water jet tests in the St. Claire River, Detroit, were able to divert oil 13 feet in a 4.2 knot current and 35 feet in a 1.6 knot current.[31] Deployment scenarios also include boats anchored at a diversion angle with each boat deploying one plunging water jet over the side. This deflects oil in a cascade effect away from a sensitive area or toward a containment area.

Plunging water jets are most effective suspended from vessels to deflect or concentrate oil. They can also be used in permanent installations such as under piers and low-lying bridges to prevent oil passage. They have relatively low power requirements compared to horizontal high-pressure jets and pneumatic boom. Maintenance is required for the pump, hoses and power pack; however, the jets are less likely to be clogged with larger orifices than horizontal jets.

3. Air Jets

An air jet directed at 45 degrees to the surface of the water will move oil on the surface by means of an induced water current. A linear series of low-pressure air jets supported by a float or suspended from a boat or skimmer will herd oil. The air jet system can be set at an angle to the advancing current in order to divert the oil to a collection system. Air jets directed horizontally can also be used to induce surface currents from a slightly submerged position. Air jet tests conducted from a prototype skimmer required one horsepower per linear foot and showed

success at speeds up to 2 knots. However, turbulence was associated with the bow wave of the submerged jet.[32] Test of an air jet oil boom were successful in diverting oil at 3 knots with 85 percent efficiency when deployed at an angle of 30 degrees to the current.[33] In 4-foot waves performance only degraded 5-10 percent. The 33-foot long boom has shallow draft and low drag. Nozzles were positioned 4 inches above the surface of the water. The air boom airflow requires low-pressure high volume air. This was obtained by a jet pump that expands and augments the airflow supplied by a high-pressure air compressor. A 750 SCFM commercial grade compressor was needed to deliver 23,000 SCFM at 3 inches of water during these tests.

This technology is suited for diversion systems in currents up to 3 knots and in waves. It can be adapted to skimmer systems or used as a stand alone oil diversion system. Air jets are less likely to clog and fail than water jets and submerged pneumatic boom.

4. Flow Diverters

Flow diverters are floating deflectors comprised of a series of paravanes or wing-like hydrofoils positioned in a vertical orientation. The interaction of the hydrodynamic forces on the paravanes creates an equilibrium state where the system attains a steady state angle to the current. The flow diverters can be easily deployed and retrieved by controlling the angle of attack of the paravanes with control lines that also function to hold the paravanes parallel to each other similar to the current rudder application. The diverters can be easily retrieved to shore by one person to allow vessels or large debris to pass. Small debris will flow through the system. The paravanes deflect the surface current and direct it toward the mooring location. In shallow water, the paravanes set up a spiral circulation pattern in the water column. The oil is diverted in the direction of the changed surface current. The strategy is to deflect oil into an area of the river or shore where currents are slower and conventional containment and cleanup devices can be used. It can also be used to divert oil away from sensitive areas. Field tests conducted on the St. Lawrence River proved successful to divert 90 percent of plastic pellets simulating oil into a low current tributary when only 40 percent were naturally diverted there.[34] The field test use huge paravanes 16-feet deep and 32-feet long. This size was selected to achieve a deflector height of one-third the water column depth to produce a spiral circulation pattern down the river similar to those produced in small-scale flume channel tests. Flume channel tests with oil use deflectors 3-inches deep and 5-inches long.

The concept is sound and has merit for fast water oil diversion applications although turbulence can be a problem at the trailing end of the paravane. This can be reduced by limiting the angle of attack of the paravanes to four degrees.[34] The use of large paravanes for deep-water applications may not be necessary. Only the top layer of water needs to be directed to influence the oil direction. The flow diverter system will also be effective in shallow rivers where use of boom is not practical due to blockage of the current flow. Oil diversion in navigable rivers and coastal areas can also be achieved by using several sets of paravanes in a cascade manner as seen in Appendix M, Figure M-1. The oil is herded to shore where currents are slower and conventional booms and skimmers can collect and remove the oil. The diverters also show promise to be effective at concentrating oil into narrow rows for skimmer collection. This can be accomplished by towing a flow diverter system off both sides of a vessel. The oil will be directed by the deflectors into the wake of the vessel where a trailing skimmer can collect it. This could also be accomplished by mooring two opposing diverter systems in a river or coastal current.

5. Floating Paddle Wheels

The Paddlewheel Boom™ (patent pending) , manufactured by Oil Stop Inc., of Harvey, Louisiana, generates a surface current to prevent oil movement by the rotation of floating paddle wheel segments connected by universal joints.. It consists of sections 8-feet long and 30-inches in diameter fabricated from high-density semi-rigid closed cell polyethylene foam. A steel drive shaft through the center of the boom connects to other sections with a universal joint and is powered by a rigid drive shaft to an engine on shore or aboard a boat. The current created by the rotating paddle wheel can be used to repel advancing oil or to push or concentrate oil or other floating materials in a desired direction, as seen in Figure 23. It can be towed by two vessels in a catenary shape or can be moored in a exclusion or diversionary mode. It is very efficient at transferring energy to the water, only requiring approximately 0.25 horsepower per linear foot of boom. It can repel oil in currents up to 4 knots in a diversionary mode. Tests at OHMSETT with a tight "U" configuration produced significant turbulence and waves that caused oil entrainment in the water column.[35] This effect may have been amplified by the very tight radius of the boom needed to fit into the test tank. This shape focused waves and current to the center of the boom. The transfer of energy to the water is so efficient that care must be take to reduce turbulence by slowing the rotation of the boom.

The Paddlewheel Boom™ would be effective in a permanent installation around a water intake or as a deployable oil diversionary system. It could also be used to facilitate oil dispersion at high rotation speeds if required. It may also be effective for in situ burning of oil. It has a very efficient and low power requirement. There are fewer modes of failure of the paddle wheel system compared to the pneumatic boom or water jets systems.

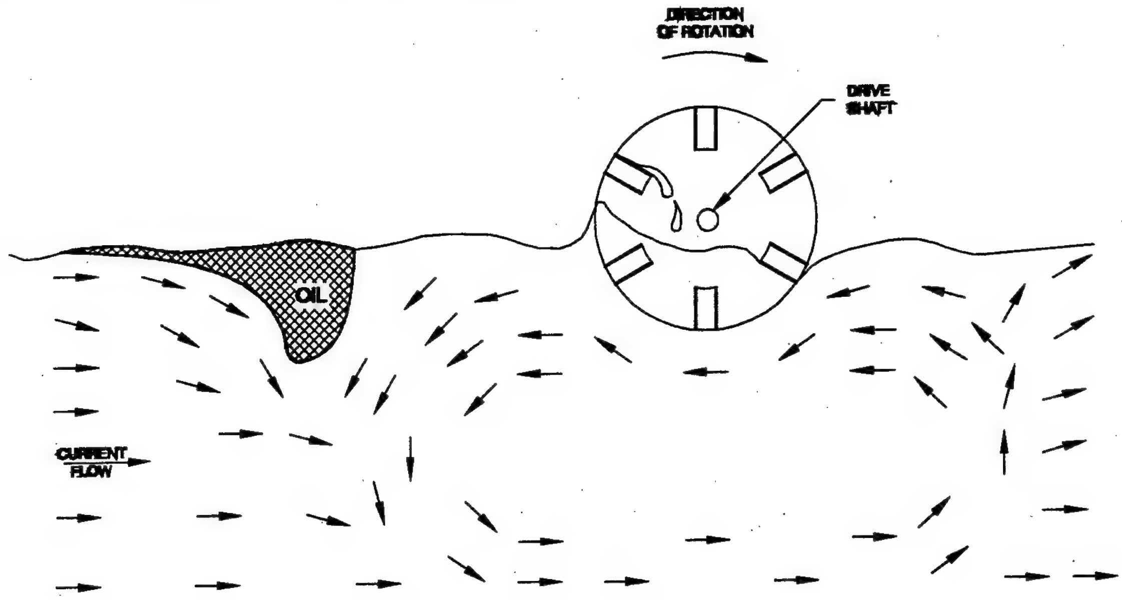


Figure 23. Paddlewheel Boom™ Creates a Counter Current to Stop the Oil

6. Earth Dam

Dams can be built in shallow rivers, culverts and inlets using hand tools or heavy machinery as available. Pipes are used to form an underflow dam to allow water passage out while oil stays behind, as seen in Figure 24. The inlet of the pipe is cut at an angle to permit a larger entrance area for the water in order to reduce the inlet velocities and the possibility of oil drawdown due to formation of vortices. This technique is effective for waterbodies less than 2 feet deep where flow volume can be accommodated by pipe flow. Vortices can also be reduced by placing sorbent pads on the oil above them.

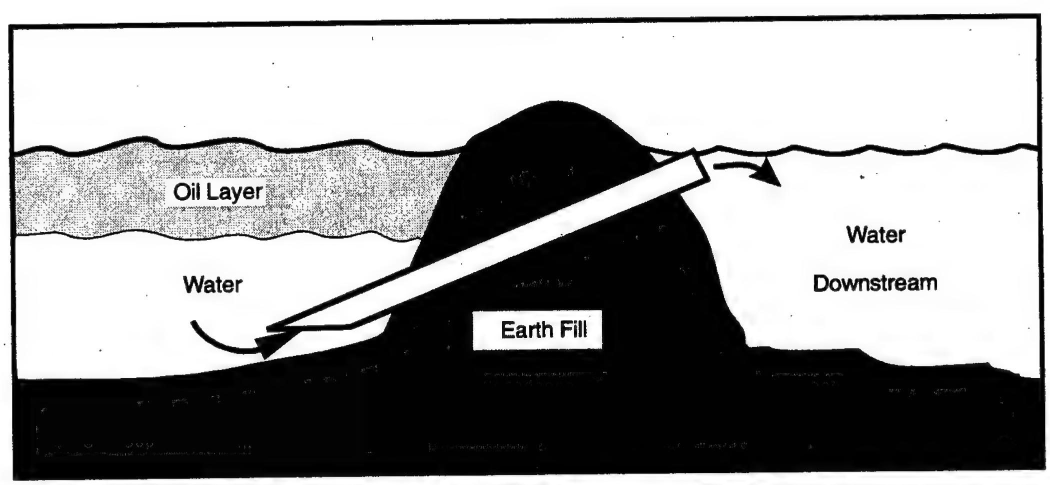


Figure 24. Earth Underflow Dam

E. Other Options Not Investigated

This investigation concentrated on mechanical methods to control and contain oil in high currents. Other options available may be effective but they are not covered in detail.

1. Sorbent boom

Sorbent booms are used for removing thin oil layers and sheen. They adsorb oil and sometimes water. Over time they become heavy and sink lower into the water. They are generally useful for slow current use and are not recommended for fast currents except as secondary containment behind an oil collection pocket near shore. Sorbent booms are typically disposable and not constructed to withstand the high forces in fast water conditions.

2. Chemical Dispersion

Dispersion of oil using surfactants is generally only allowed offshore and in coastal waters at least 30 feet deep where good flushing characteristics exist. There is no fresh-water chemical dispersant on the market however, EXXON is currently developing one. Dispersants could be effective in large volume fast flowing rivers in certain situations, but approval may be difficult to obtain. The USCG Eighth District in New Orleans, Louisiana has indicated that it would consider dispersant use on the Lower Mississippi River if a fresh water dispersant is developed.[36]

3. Chemical herding

Chemicals that effect the surface tension of water can be used to herd or push oil into a smaller area creating a more concentrated slick. This process is generally used in confined low-current areas to facilitate pickup or skimming and woul not likely be useful in a fast water environment.

4. Visco-Elastic Agents

Visco-elastic agents are chemicals that cause oil to gel and become semi-solid in large flat sheets or clumps that float. This allows the oil to be picked up by debris-type handling equipment. Conventional skimming equipment cannot collect this material and it cannot be pumped once it gels. Oil does not usually leach out of the gel.

5. Pretreatment of Shorelines

Chemicals can be used on shorelines and other surfaces that tend to prevent the oil from adhering to it. They can be applied to shorelines to prevent oil from sticking to the beach and penetrating into the substrate.

6. In-situ Burning

Oil contained by fire resistant boom or other barriers and concentrated to a minimum thickness can be burned on the surface of the water. This is usually done at sea or in remote land-based areas, where smoke will not impact high-density population areas. Fire resistant boom is relatively fragile and becomes may become weaker when subjected to intense heat from the burn. It is unlikely that it can withstand high current forces for very long. Approval to burn in inland rivers may be difficult to obtain. In-situ burning must be conducted within the first day or two of the spill when the oil is still fresh containing the flammable light aromatics. Burning is very effective at reducing the volume of a spill and is usually not toxic to the marine and atmospheric environments.

6. HIGH SPEED OIL SKIMMERS

A. Introduction

High-speed skimmers are devices that can collect and remove oil from the surface water flowing at a relative velocity of one knot or greater to the skimmer. This requires that the device picks up the oil or separates it from the water flow underneath in order to prevent or reduce oil entrainment in the process. They can be used in a stationary mode in fast currents or as high-speed advancing skimmers. Several representative types of skimmers presented in Appendix N have proven successful at oil removal in fast currents. Length over all (LOA) and displacement of the skimmers are provided.

The effectiveness of a skimmer is mainly assessed by a combination of two performance indicators, oil throughput efficiency and oil recovery efficiency at the particular current and wave height tested. Throughput Efficiency (TE) is the percent of oil recovered compared to the total amount of oil that the skimmer has encountered. This is an important consideration if that oil escapes and it will impacts sensitive areas or if it cannot be encountered again for recovery. Recovery Efficiency (RE) is the percent of oil recovered (including bound water in emulsions) compared to total fluid volume recovered, oil and free water. Oil Recovery Rate (RR), another important performance indicator, is limited by the amount of oil the skimmer can collect and by its maximum pumping rate. As speed increases, the oil encounter rate goes up and the skimmer throughput and recovery efficiencies generally decrease while the oil recovery rate may go up or down. Any reasonable amount of oil collected is considered successful at the higher velocities (3 to 6 knots), since the conditions are adverse and any oil that is not collected will likely impact the shore. Environmental damage and cleanup costs are much more extensive once oil drifts ashore dictating that every effort should be taken to collect it while it is still on the open water.

Data are presented for many of these skimmers to define their general capabilities. However, direct comparison between skimmers is not recommended because the test conditions often vary substantially. Another factor to consider is the logistics involved in transporting and deploying the equipment. Reliability, ease of use and the operating skill required to use the skimmer efficiently are also important considerations.

B. Inclined Plane

Inclined or submergence plane skimmers force the oil to follow an incline below the surface of the water and the oil's buoyancy causes it to rise and separate from the surrounding water. These skimmers are usually more effective in waves because the oil is displaced from the surface of the water before separation. Furthermore, both light and heavy products are collected efficiently. If there is little difference between the density of the oil and water, some oil may escape at high velocities before it can rise into the collection well behind the inclined plane. There are two types of inclined plane skimmers as seen in Figure N-1, static and dynamic.

1. Static Inclined Plane

The static incline plane skimmer consists of a fixed incline at the bow that separates oil during three phases while advancing or held stationary in a current. Oil is first separated from the water by an adjustable scoop that takes a slice of the flow at the bottom of the incline. The oil and some water enter a large collection bay where the oil rises and the remaining water is allowed to escape out the bottom and lower back portion of the bay. During this second stage, plates or baffles are present below the collection bay to separate the faster flowing water from the oil above and to assist with gravity separation. Oil is further concentrated in a collection and separation well during the third phase by a self-adjusting weir where the oil is removed by a positive-displacement screw pump. The LPI skimmer was developed and tested in the 1970's however, it did not become commercially available until recently. It is now distributed as the HIB skimmer by Hyde Products Inc, of Cleveland, Ohio. The original LPI design was improved by Webster Barns Inc. of Rowayton, Connecticut. The design improvement is the hydrodynamic induction bow foil,as seen in Figure N-1, that assists with oil entry down the plane also helps reduce bow wave interference.

Tests recently conducted at OHMSETT in late 1996 at speeds from 3 and 5 knots on the HIB-20 showed that the skimmer consistently had a RE of 90 to 98 percent.[37] It had a TE of 41 percent at 3 knots with a reduction to 24 percent in the four and five knot tests. The average oil encounter rate was 306 GPM. The oil RR was 147 GPM at 3 knots with a reduction to 73 GPM at 5 knots. The skimmer was evaluated attached inline to the apex of the USCG Fast Sweep™ V-shaped boom using short tapered boom sections at the bow of the skimmer. At speeds above 3 knots, the deflection boom configuration caused the oil to concentrate into a narrow and vertical band that allowed some oil to pass under the scoop. The distributor believes that the TE would be increased significantly if the deflection boom were attached directly to the skimmer. OHMSETT data from the first generation inclined plane LPI skimmer seems to substantiate this claim. LPI skimmer tests showed that a TE of 93 percent was attained in calm water and a TE of 74 percent was realized in 1.1-foot waves. Longer versions than the 20-foot HIB skimmer tested have a theoretical advantage to have higher performance capabilities.

The HIP skimmer has no moving parts except for the pump, so reliability is high and maintenance is low. It can be configured as a VOSS skimmer with or without a side sweep system, as an inline skimmer in the apex of a boom or outfitted to be self-propelled.

2. Dynamic Inclined Plane (DIP)

The dynamic inclined plane skimmer was also developed in the 1970's. It has been commercially available since then by JBF Environmental Services Inc. of Ellsworth, Maine,and is designed to operate at 0 to 3 knots. A belt is rotated down the submergence plane at the speed of the vessel over the water. This facilitates the flow of oil down the incline and up into the collection well. Although the belt adds mechanical complexity, it allows oil to be collected in stagnant water by inducing flow to the collection well. Oil rises into the collection well due to its buoyancy. This is facilitated by several C-channel baffles near the bottom of the well. A plate along the bottom of the collection well separates the faster flowing water below from the oil/water separation process above. An adjustable outlet back-plate at the bottom aft portion of the well allows water to exit the well. This adjustment controls the amount of fluid (oil and water) that is allowed to enter the well at the bottom of the ramp and must be set properly for the best results. The DIP is effective with both light and heavy oils although if the oil is very dense, it may go under the collection well during high-speed operation due to its limited buoyancy.

Figure 25. Dynamic Inclined Plane Skimmer at OHMSETT

There are many configurations of the DIP from small portable units to large ships. The USCG recently procured six DIP skimmers for the USCG VOSS at their three Strike Teams. These High Speed Skimmers attach to the apex of the Fast Sweep™ V-shaped boom as an inline skimmer as seen in Figure 25 above. At tests above three knots, the apex of the boom lost some freeboard due to dynamic hydrodynamic forces pushing down on the skirt. This however, did not effect the TE that remained constant between 3 and 5 knots. A deflection boom with less draft at the apex will reduce the flow of water into the attached skimmer and should ensure that freeboard is maintained for rough water conditions.

Tests at OHMSETT on the USN 3001 self-propelled DIP showed that it is effective at skimming up to 2.5 knots.[38] The 26-foot long skimmer can transit at 5 knots and onboard oil storage capacity is 1,400 gallons. It has two short retractable deflection arms that increase its sweep width to 15 feet. In calm conditions, TE ranged from 80 percent at 2.5 knots to over 95 percent at 1 knot. In a 1.5 to 2.5 foot harbor chop the TE decreased slightly to 74 percent at 2 knots and to 84 percent at 1 knot. Recovery efficiency and oil recovery rate were not reported. Oil is pumped from the top of the sump using a positive displacement pump when the well is full of oil so RE is usually high.

C. Zero Relative Velocity (ZRV)

The zero relative velocity skimmer refers to an oleophilic surface that moves at the speed and direction of the passing oil in order to maximize contact and minimize shear velocities at the pickup zone. This also reduces the head wave that will form at high speeds and tend to push oil away when an object is dragged over the surface of the

water. There are three types of ZRV skimmers that are of interest as seen in Figure N-2, however, only the rope mop ZRV is commercially available.

1. Rope Mop ZRV

A rope mop consists of oleophilic fibers that are woven into a rope that floats on the surface of the water. A set of ropes is suspended between a catamaran hull. They are propelled between the side hulls at the speed of the vessel over the water. Oil adheres to the rope and it is brought aboard were water continues to drop off along the way. The oil is then completely removed from the rope as it goes through a wringer up near the bow of the skimmer. The oil flows into a sump where it is transferred by a pump or suction hose. The rope mop ZRV skimmer is produced by Oil Mop Inc. (OMI) of Belle Chasse, Louisiana, and by Ro-Clean Desmi A/S of Odense S, Denmark. They are available in a wide range of sizes, configurations and capacities from small portable units to large multipurpose vessels. They can recover a variety of oil viscosities but are most effective with medium viscosity oils. Mops function well in a variety of wave conditions and are effective in debris and broken ice and can recover lighter oils better than brush skimmers.

The OMI ZRV skimmer was tested at OHMSETT at speeds from 1 to 5 knots.[39] Above 3 knots oil was lost from the mop when it came up around the stern rollers and created a rooster tail effect. A splashguard modification reduced those losses. In calm water at 5 knots, the skimmer recovered 13.9 m^3/hr with a TE of 43 percent and RE of 48 percent. Efficiencies improved at lower speeds but the RR decreased slightly at 3 knots to 12.8 m^3/hr and down to 4.3 m^3/hr at 1 knot. The TE improved to 76 percent in the 2 to 3 knot range and RE improved to 62 percent.

The Ro-Clean Desmi Pollcat skimmer line also uses ZRV rope mops suspended below catamaran hulls. The larger skimmers also function as workboats with large open deck areas. Tests conducted on the 15.5-meter long MV KYRRE with 12-inch diameter rope mops in medium viscosity crude oil at speeds between 2 and 6 knots, showed a RE of 80 to 100 percent and a RR of 40 to 50 tons per hour. Throughput efficiency could not be measured in the field. Recovery efficiency only dropped 20 percent from 2 to 6 knots but the faster oil encounter rate still allowed 40 tons per hour RR at 6 knots in 3-foot waves.[40]

2. Belt ZRV

ZRV belts are oleophilic materials usually consisting of a synthetic grass mat like material, Astroturf, used for collection of viscous oil with an inner layer of polypropylene felt that absorbs light oils. Several systems were developed and successfully tested in the 1970s. These included the USCG and the Bennett belt skimmers.

a) USCG ZRV

The USCG ZRV was a 30-ton oleophilic belt skimmer that was developed in the 1970s. It was 45 feet long, 22 feet wide and had a draft of 3.6 feet. The skimmer processed two continuous 3.5-foot wide, 126-foot long sorbent belts between the catamaran hulls at the forward velocity of the vessel. The belts were drawn up over drums in the rear of the vessel where they were scraped and then squeezed in a series of rollers positioned around perforated drums. The belts were then routed over powered rollers to the front of the vessel back onto the slick as seen in Figure N-2. A spring tension guide was positioned behind the belts in the front of the skimmer to ensure the belts contacted the water's edge close to the bows. A collapsible stern mounted A-frame was used for towing an oil storage bag. The skimmer was self-propelled and could transit at 10 knots and skim oil from 0 to 6 knots.

The USCG ZRV performed extremely well in currents from 1 to 6 knots and in calm water and in choppy waves up to 2.25-feet during tests at OHMSETT. Oil thickness of the slick and viscosity was varied and heavy oil and a thick slick were the most difficult to recover. In calm water proceeding at 6 knots, the skimmer recovered 87.3 m^3/hr with a TE of 95 percent and RE of 64 percent. A 1.6-foot harbor chop reduced performance slightly in 6 knots with a RR of 74.1 m^3/hr, a TE of 81 percent and RE of 56 percent. At lower speeds, the TE improved to 95 percent and RE was approximately 65 percent. At 2 knots the RR was 28.4 m^3/hr and at 4 knots the RR was about 45.5 m^3/hr.[41 & 42] It was the most successful fast water skimmer tested at OHMSETT but it was never commercially produced. The systems were mechanical complexity that resulted in reliability problems.

b) Bennett ZRV

Aqua-Guard Spill Response Inc. of North Vancouver, British Columbia, Canada developed an inclined submergence ZRV belt skimmer shown in Figure N-2. It slices the surface of the in coming water to improve oil recovery

efficiency. Oil that is not picked up by the sorbent belt can be recovered by a weir at the rear of the collection chamber. Despite all of these features, the Bennett Mark 6E skimmer did not recover oil effectively above 3 knots. TE was about 80 percent at 2 knots but it dropped to 30 percent at three knots in calm water.[43] One-foot waves caused TE to drop drastically to 40 percent at 1.75 knots. RE did not change significantly with speed increases but it was effected by oil viscosity. RE was 78 percent for heavy oil and 60 percent for light oils. The average highest RR was 24.5 m^3/hr for heavy oil and 8.3 m^3/hr for light oil.

D. Quiescent Zone

Quiescent zone skimmers function in high currents mainly by providing a sheltered area for the oil to collect away from the fast water currents underneath that will tend to entrain the oil under the collection system. The oil is then removed by weirs, suction or brushes. There are three types shown in Appendix N, Figures N-3 and N-4 that are effective in fast water currents.

1. Expansion Weir

The expansion weir works using several principles to remove and separate oil in a fast current. A diversion boom funnels oil into the narrow mouth of the skimmer. A surface slice is taken using a deflector to separate the concentrated oil from the water below. The water is forced to expand into a larger collection area that causes the velocities to slow, facilitating gravity separation of the oil. A floating weir lip further separates the oil from the water in a sump in the aft section of the skimmer where a pump or suction hose removes the oil. Water exits just forward of the weir towards the rear of the skimmer, which is controlled by a manually adjustable hydroplane. The Fasflo skimmer is manufactured by Vikoma International of Isle of Wight, United Kingdom and it is shown in Figure N-3. Two different sizes are available for rivers and coastal applications. There is no data available for the skimmer in controlled conditions.

2. Circulation Weir

A circulation weir skimmer called the Hydrodynamic Circus has recently been developed by Blomberg Offshore AS of Frolunda, Sweden. It can be used for high-speed sweeping or as a stationary system deployed in fast flowing waters to collect and concentrate oil in an artificial lagoon that facilitates oil recovery with a high recovery efficiency.[44] It is built similar in shape as small dory and operated as a rotation chamber for oil/water separation. The Circus is used with a boom off one side that deflects oil into the circular lagoon. A bottom plate prevents fast flowing water below from entraining the oil out of the protected lagoon. The boom has a draft approximately one half the height of the entrance opening in the side of the skimmer. This allows the water to exit under the boom while oil remains in the lagoon in a circulation pattern on the surface as seen in Figure N-4. A shallow guiding boom forces oil to the center of the lagoon where it is removed by a floating weir lip attached to a positive displacement screw pump or suction hose as desired. It is designed to function in 0.5 to 3-knot currents. The system is available in several sizes for small boats and large vessels as a VOSS skimmer. It can also be used on the side of a riverbank, bulkhead or along a coastal area. There is no performance data available for the skimmer in controlled conditions.

3. Streaming Fiber Skimmer

The streaming fiber skimmer, shown in Figure N-4, functions in high currents by using long fibers that slow down the current and oil along the surface. This limits entrainment by dampening the turbulence with free flowing fibers. and allows the oil to thicken at the aft end of the skimmer where it can be removed by conventional means such as a weir or sorbent belt. The surface water also slows down, but it is forced out the bottom of the skimmer to rejoin the main stream again. In field tests, the skimmer was able to collect oil at speeds up to six knots.[45]

4. Recovery Channel with Brush Conveyor

The Lori skimmer is manufactured by Oy LMP Patents Ltd AB of Loviisa, Finland and distributed in the US by Hyde Products, Inc. of Cleveland Ohio. It uses an oleophilic brush-conveyor system that rotate up into the slick to pick up oil and debris on the bristles of a brush. Several continuous loop brushes are mounted on chains. The oil is scraped and squeezed off the brushes by finger-like cleaners at the top where the oil is gravity fed into a sump and storage tank. The skimmer is effective in higher currents because the area where the brushes contact the oil is protected from entrainment in a recovery channel that has a bottom plate. Typically, the oil is deflected into the channel by the hydrodynamic flow of the water through the rotating brush conveyor. Clarified water recirculates

back to the collection area. The channel is located inside a dedicated skimming vessel or inside a removable side collector unit for VOSS applications. These skimmers are effective in currents up to 3 knots. They recover heavy oil and emulsions very well, but are less effective in fresh light and medium viscosity oils as demonstrated in OHMSETT tests in 5, 600 and 10,000 cSt viscosity oil.[46] Recovery efficiency is high and this type of skimmer is not adversely effected by waves.

E. Lifting Belt

A lifting belt skimmer uses a porous oleophilic belt that rotates oil up an open incline. An induction pump behind the belt helps draw the oil into the system as water passes through the belt and oil is deposited on it, Figure N-5. The oil and debris are scraped and squeezed off the belt at the top where oil flows into a collection well and debris is caught by a screen. These units, manufactured by Marco Pollution Control of Seattle, Washington, are usually self-propelled advancing skimmers. They can skim up to 3 knots but effectiveness drops off above 2 knots. The downward slope of the belt tends to force the skimmer down into the water at higher speeds.

OHMSETT tests of the Marco Class V skimmer resulted in a TE of approximately 75 percent at speeds up to 2 knots in calm water, but TE dropped off to 30 percent at three knots with heavy oil.[47] RE remained constant over speed changes at 90 percent. RR varied between 3 and 11 m^3/hr from 0.5 to 2 knots, respectively, with 8 m^3/hr at three knots.

F. Rotating Brush Wheel

The rotating brush skimmer is manufactured by Lamor of Porvoo, Finland and is distributed in the US by Quali Tech Environmental, Inc. of Chaska, Minnesota. Its oleophilic brushes rotate down into the oncoming oil forcing it deep into the bristles aided by the buoyancy of the oil as seen in Figure N-5. This facilitates a higher throughput efficiency and recovery rate and enhances the recovery of lighter oil than with the upward rotation used in the Lori brush skimmer. The rotation sets up a current that draws oil into the skimmer. Tests conducted by the Swedish Coast Guard in a 1.5 knot current showed that the Lamor had an average RR of 16 m^3/hr, while the Lori skimmer had an average RR of 5.4 m^3/hr using a Norwegian North Sea crude oil emulsion.[48]

G. Surface Slicing

Several high-speed skimmers separate oil from the water mainly by slicing the surface of the water just below the oil layer as seen in Figure N-6. This slicing mechanism facilitates separation but it is generally adversely effected by waves.

1. High Current Oil Boom

A low drag rigid structure boom was developed to operate in currents up to 6 knots, in low wave conditions. It utilizes a slightly submerged slotted hydrofoil to skim a thin layer of oil and water into an attached sump where the kinetic energy of the high speed flow is dissipated and the oil and water are separated by gravity.[49] The retained oil is recovered by a weir at the rear of the boom. TEs as high as 99 and 87 percent were measured at 4 and 6 knots respectively, in calm water. A mean RE of 54 percent was measured in calm conditions. In one-foot harbor chop the mean TE dropped to 42 percent and the mean RE dropped to 18 percent. The Streamlined Oil Boom Skimmer is an improvement of High Current Oil Boom that also had performance degradation in waves. These skimmer/boom prototype systems shown in Figure N-6 were never produced commercially.

2. Multi-Purpose Oil Skimmer System

This skimmer was designed to follow the waves while the surface of the water is sliced to separate the oil layer from the water below. It consists of a U-shaped vessel with a buoyant tank system on both sides and at the aft end. Between the side hulls, two horizontal flaps are hinged to the bottom structure. Both flaps are connected to floaters that keep the leading edges just below the surface. A wave dampening mechanism is used to assist with slicing the surface in waves. A one-fifth scale model was tested in a tow tank and had high TE in 1 to 3 knots in calm water and in 3-foot waves at 2 knots. The RE was low at 20 to 50 percent.[50] The full-scale skimmer was built with the dimensions 106-feet long, 38-feet wide and 4.8-foot draft. This skimmer would be useful for operations in large bays and offshore.

3. Russian Oil/Debris Skimmer

The Soviet harbor oil/debris skimmer, Model 2550/4 dimensions are 57-feet long, 14-feet beam and a 5.1-foot draft. It can be operated in advancing and stationary modes because it uses a ducted propeller system that can pull oil into itself. Oil is drawn over a weir into a large basin in the forward portion of the vessel by the current from the ducted propeller. The fluid travels through a coke filter and adjustable sluice gates, then over weirs and out through the main propulsion duct. Oil leaves the basin through an adjustable basket strainer. It then flows over an overflow weir, and is drawn into a separator tank on one side of the vessel and then through a second tank on the other side. It underwent tests at OHMSETT where the best performance was a TE of 80 percent and RE of 85 percent at 2 knots in calm waters.[51] The average RE was 66 percent for all tests dropping to 48 percent in 2 foot harbor chop. The best RR was 8.6 m^3/hr at 1 knot.

H. Free Floating Adsorbents

Free floating adsorbents can be used to recover oil in very fast moving currents in restricted waters and in open waters with large waves where other methods cannot be used effectively.

1. Trailing Rope Mop

The trailing rope mop is an oleophilic free-floating rope mop skimmer that is deployed from a vessel of opportunity. Paravanes are used to pull a series of five 192-foot long rope mops out to the side and aft of the vessel in the form of a net,, while proceeding at a maximum speed of 4 knots. After the net becomes saturated with oil it is retrieved and processed through the squeeze rollers and scrapers in a batch mode that takes approximately 5 minutes. Since the polypropylene fibers float, they conform to the waves and have good contact with the passing oil. Recovery rates vary with oil thickness but would be approximately 56 m^3/hr for a 2mm slick thickness.[52] The Force 7 system fits inside a 20-foot container and weighs 6.4 tons dry. It is manufactured by Oil Pollution Environmental Control Limited of West Yorkshire, United Kingdom and is distributed by Applied Fabric Technologies, Inc. of Orchard Park, New York. It is designed to operate in seas up to 14 feet high. Smaller units can be made for coastal and inland river applications. This system can also be deployed in a stationary mode in a fast moving current.

2. Drifting Adsorbent and Recovery

The sorbent is distributed onto the slick by use of a pneumatic broadcaster for this technique. An inclined open wire-mesh conveyor belt is used to remove the saturated sorbent downstream from the water with the aid of a deflection system. Ideally, this requires biodegradable sorbents because there will be a quantity that will not be recovered. The recovered oil and water are removed by squeezing the sorbent in a converging press belt press. The sorbent can then be reused on the slick. Tests at OHMSETT with sweep speeds up to 5 knots in waves and in calm water resulted in a TE of 45 percent to nearly 100 percent, respectively.[53] The RE was between 38 percent to 79 percent. In these tests, open cell polyurethane foam in the form of small cubes was used. This type of system will be effective in high currents and in shallow rivers where conventional oil containment methods are not effective.

7. SUPPORT EQUIPMENT

Support equipment in fast-water spill response is geared to delivering and deploying the recovery systems quickly and safely. This requires strong and sturdy equipment to withstand the forces involved in high current situations. Transportation of equipment and debris is accomplished with trucks, boats, barges and sometimes aircraft. Recovered oil must be stored and transported. Good communications between the field teams, other resources and the command center are essential for effective operations.

A. Boats

Boats and larger vessels are required when deploying equipment in wide rivers and on open coastal areas. High drag forces exerted on boats and boom in fast currents make deploying equipment and maneuvering on the water very difficult and potentially dangerous. The open bay and coastal regions usually have higher that require larger boom and boats. It is very important to have enough horsepower to respond to these high forces when towing boom. Boom drag and mooring angle considerations should be used to determine the boat bollard pull required for the scenario and operating area at hand. Adequate horsepower should be selected with assistance from the boat manufacturer based upon the calculated towing forces with a margin of safety. Generally, one horsepower is

required for 20 pounds of force exerted on a boom but this will vary based upon the boat and propulsion type. Proper boat selection is also very important. Boats and barges should be selected to that make the tasks easier and safer to perform. Vessel configurations that allow for boom and equipment to be easily pulled overboard and retrieved through a bow or stern ramp that can be lowered to the water's edge are very useful. Boat stability, working area, visibility, deck arrangement, freeboard, seakeeping, propulsion type and horsepower are important factors. Towing points located forward of the rudder or outboard motor is desired for good maneuverability.

1. Conventional

Conventional displacement boats and barges will be adequate in most situations. They can handle large loads and can transit reasonably fast. In rough seas, they have average seakeeping abilities. Catamarans can provide increased roll stability and deck area. Planing hulls are faster and can be used for lighter load situations where transit speed is important.

2. Jet Boats

Jet drive boats are preferred for shallow rocky areas to facilitate access and avoid propeller damage or fouling common on conventional propeller driven boats. This type of boat can maneuver very easily. Many inland-dedicated skimmer boats are provided with jet drive.

3. Airboats

Airboats are special flat-bottom boats that are propelled by an engine and caged aircraft propeller near the rear of the boat. They vary from 18 to 30 feet in length and 8 to 15 feet in width. Larger airboats can carry payloads up to 7,500 pounds. Rudders aft of the propeller control its motion. The bottom is sometimes protected with a high-density polymer layer that reduces friction over land and marshes. Airboats are stopped by reducing power and quickly reversing the course of the boat. They can operate on ice, shallow water, swamps, wetlands and level ground. Alaska Clean Seas uses airboats to transport people and boom on the North Slope of Alaska.

4. Air Cushion Vehicles

Air cushion vehicles (ACV) ride on a cushion of air generated under the hull. The air cushion is contained by flexible skirts that partly inflate and extend around the perimeter of the hull. They are propelled like airboats by airplane props at the rear of the vessel. Air cushion vessels and barges can be very large and carry many tons of equipment and supplies and can operate over water, ice and level land. The Canadian Coast Guard has used them for spill response and for breaking level ice. A study to determine the utility and cost of a dedicated oil spill response ACV that can carry a payload of 90 tons and transit at 28 knots was conducted. The cost of this vessel capable of responding to an offshore 2,500 barrel per day oil blowout was about $7 million Canadian dollars.[54] The cost of outfitting a 22-foot wide wire brush ZRV belt skimmer over the bow of the Bell Voyageur ACV and providing an onboard oil incinerator was estimated at $1.1 million Canadian dollars. Smaller inland ACVs with less payload capabilities would be significantly less expensive. ACV are more expensive to purchase and maintain than conventional craft and airboats of similar displacement but will cause less damage to marsh and wetlands vegetation than airboats.

B. Barges

Oil must be stored when it is recovered and barges are the most reliable if they are available. Several types of small barges used for shallow water can be transported by truck to the spill site. Some are designed to attach to each other side-by-side in modular form. The Marine Spill Response Corporation (MSRC) has developed shuttle barge system for shallow-water oil spill cleanup.[55] Two 48 feet by 8 feet by 4 feet pontoons can be quickly joined to form a barge consisting of four tanks with a total capacity of 420 barrels. The entire system of two pontoons weighs 36,000 pounds. Draft empty is 0.7 feet and draft full is 3.3 feet. The system can also be configured with a hydraulically powered drive unit and side mounted sweep with a weir skimmer. Lori also produces a similar aluminum barge system outfitted with a brush skimmer at the aft end with deflection boom. It has a 30-feet length, 8-feet beam and 3-feet freeboard and weighs 5,000 lbs. Draft empty is 0.7 feet and draft full is 2.3 feet with a 99-barrel capacity. It can also be joined to a sister barge for a 200-barrel capacity.

C. Temporary Oil Storage Devices

The preferred method for oil storage and removal are tank and VAC trucks if the cleanup site is accessible. If they are not available or oil storage is required at sea and barges are not present, then temporary oil storage is required. Oil storage by use of portable tanks and bladders is useful for locations that need storage quickly. These devices are relatively lightweight and can be transported by truck, boat or aircraft to the spill site. They are made of reinforced fabric and are more susceptible to damage by groundings and abuse than barges. They come in many different sizes and configuration options. Towable bladders can be used behind skimmers and inflatable barges with open tops facilitate debris handling and oil offloading. Oil pits can also be dug with earth moving equipment. The pits are then lined with plastic for shore-side oil containment.

D. Aircraft

Response to fast water spills requires speed. If equipment cannot be pre-staged or the spill is in remote areas, aircraft can be used to transport equipment and people to the scene. Aircraft can also be used to deploy anchors and boom. They are also used for surveillance of spills and quickly selecting good recovery sites. Aircraft are also used for distributing dispersants.

1. Fixed Wing

Airplanes are used to transport heavy loads and large numbers of people. Knowing the cargo bay size and packing requirements is important for planning purposes and fast loading. Use requires availability of runways or aircraft with pontoons or boat hulls for water landings.

2. Helicopter

Helicopters are very useful for delivering light loads of people and equipment to remote locations. Equipment is often carried in a sling load beneath the aircraft. Since they are very maneuverable and can hover in position they can be used to deploy boom and anchors. Care must be take in these operations because helicopters can become unstable and crash if a sudden heavy side load is exerted on them from a line attached to the ground.

3. Unmanned Aircraft

Unmanned remotely piloted aircraft can be used to obtain airborne video and infrared imagery of a spill site. The images are transmitted back to the command post where they can be seen real time. They are less expensive than manned aircraft and can be easily transported to the spill site by truck or car. Many different types are available in a wide range of capabilities and costs.

E. Mooring Systems

To form an effective barrier to the oil, containment booms must be held stationary. Booms are secured at each end and usually at several locations along their length. Anchoring boom in high currents is a challenge due to the high forces and fast flowing water. Small changes in the deflection angle or shape of the boom due to anchor drift can cause the boom to fail due to oil entrainment. Selecting mooring lines that do not stretch much under tension are preferred. Anchoring should be done on shore where more control is available for positioning, moving and selecting secure anchor points. In wide rivers and coastal areas, anchoring in the water is required. There is a variety of anchors available and their holding power is based on a number of factors including bottom type, weight, anchor type, scope of line and amount of chain. Various configurations of multiple anchors can be used to increase the combined holding power.

1. Anchors

To ensure that the anchor holds properly, mooring-leg tension should be held close to the bottom. This is obtained by using the proper scope of line and the appropriate length and weight of chain. Mooring legs 5 to 7 times the depth of water are recommended, as shown in Figure 26.

It is important that the mooring leg provides a good horizontal restraint to the boom without pulling it down below the surface. A buoy is connected about 10 feet from the boom to help prevent vertical tension on the boom. A paravane can be attached to the leading edge of the boom if additional buoyancy is needed An anchor retrieval line

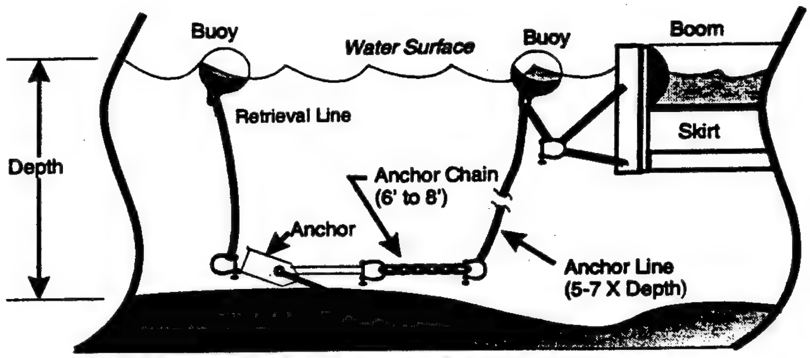


Figure 26. Typical Boom Mooring Configuration

is attached to the crown of the anchor and has a separate buoy. This aids in the positioning and retrieval of the anchor.

The most common anchor found in spill response is the standard steel Danforth®. Specialized Danforth anchors such as the High Tensile® and Deepset® may be more applicable to fast water booming because they have higher holding power and strength. Typically, the heavier 43, 70 or 100 pound Danforth anchors are used to get the holding power required. Handling the larger anchors is difficult, cumbersome and sometimes dangerous especially when deploying from a small boat. In some cases it may be advisable to pay more money for high strength aluminum alloy anchors that weigh about half that of steel anchors with the same holding power. For example, the Fortress FX-55, a 32-pound aluminum alloy anchor rated at 16,000 pounds pullout force, is used by the USCG for offshore boom mooring packages. A Portsmouth, New Hampshire Cooperative uses them for fast water booming rivers. Other anchor types available include mushroom, wishbone, plow, Porter, Bruce, pile, CPA disc and deadweight. Each has its advantages and liabilities. The mushroom anchor is effective in mud while the CPA disc anchor was developed for rocky bottoms. Holding power can be increased by adding more anchors in line or at angles to the mooring line shackle. A three-anchor mooring configuration on a shoreline is shown in Figure 27. This will also allow use of lighter anchors making deployment easier ashore or from a boat in the water.

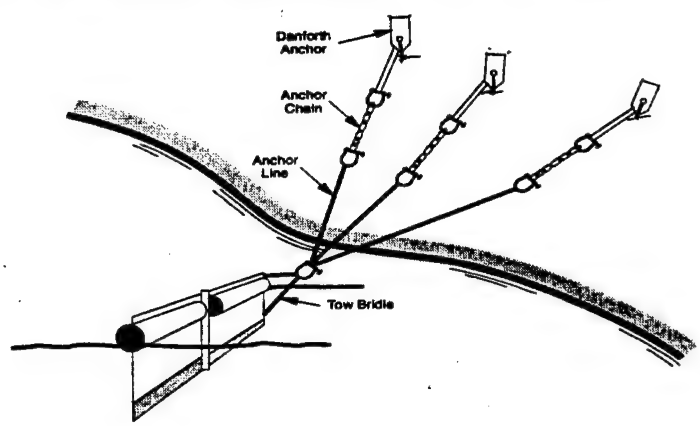


Figure 27. Multiple Anchors used to Moor Boom

2. Shoreline

Shoreline moorings are preferred over setting anchors in the water because land affords better selection and control. A big rock, tree or man-made structure can usually take the required load. The next choices are steel pipes, fence posts or T-stock that can be pounded into the soil . These posts are staggered in line along the booming direction and connected to each other with lines to prevent them from pulling out as shown in Figure 28. Screw type anchors are recommended for rocky shores. Spade anchors are useful for attachment of shore-side boom lines.

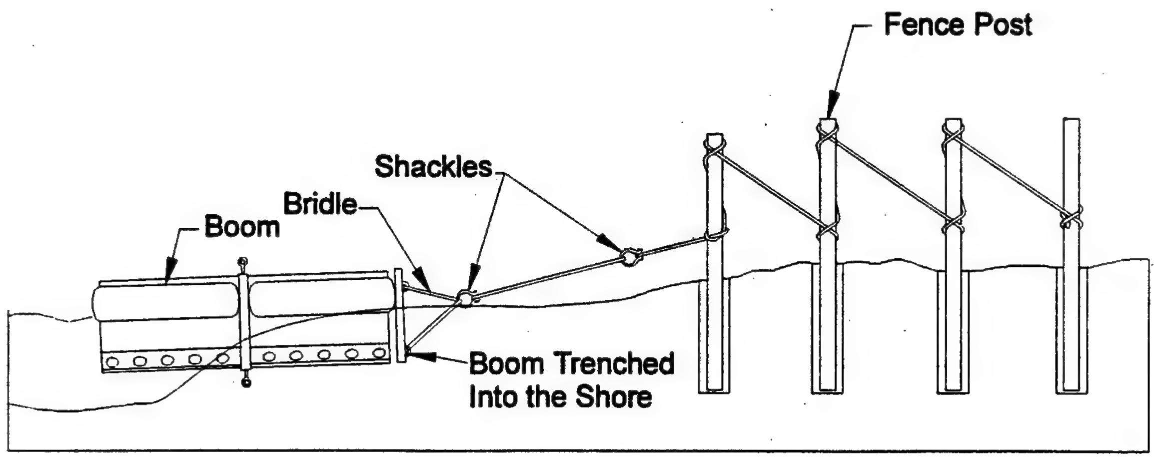


Figure 28. Typical Shoreline Boom Mooring System

3. Mooring Techniques

There are many techniques to set and attach boom to get the proper angle and shape. The upstream lead anchor should be set first with the boom trailing parallel to the current. A load should not be placed on the mooring line until it the anchor is on the bottom. The anchor can be lowered by the mooring line from a small boat however; the current may move it quite a distance before it sets. A preferred method is to use the anchor retrieval line to position the anchor while it is just off the bottom. Releasing the line will ensure that it sets close to the desired location. A spotter on shore should direct the boat to help with anchor placement. Another method to deploy an anchor from a small boat is to fake down the line and boom on shore with the shore anchor system in place and attached to the opposite end of the boom. The anchor release line is attached to the stern of the vessel. Towing the anchor quickly out to sea, causes the anchor to plane on the surface. When tension is on the boom and it is at the desired angle, the retrieval line is released by cutting a safety attachment line to drop the anchor in place. The shore crew then pulls in on the shore side mooring line to set the anchor. Quick release hooks placed on the mooring buoy assist with making connections quickly.

F. Communications

Communications between responders and with the command team is critical for the success of every response. A communications plan should address all modes of communication for all resources that respond to a spill. Radio equipment and frequencies must be selected that provide the type of coverage for the scenarios that are expected. Radio repeaters can be installed on mountainous sites to improve radio coverage in valleys. Cellular telephones are also very effective if coverage is available. Satellite telephone systems can be set up where land line or cellular telephone coverage is not available. Field personnel can also use hand signals for deploying boom and anchors. Good communications is critical in fast water operations to ensure the equipment is used and deployed safely. Team supervisors and the command center must be kept informed on a regular basis as to what is happening to ensure an effective operation. Field personnel should also be periodically briefed on the status of the operations.

G. Ancillary Equipment

Many other types of equipment are required in a spill response. Some support equipment is unique to fast water operations. Laser range finders are useful to determine distances for booming strategies and the number of boom sections and mooring line lengths required. Binoculars are required to quickly scope out good staging areas and shoreline mooring points. Binoculars are available with a compass readout that can be used to select a mooring point to obtain the desired boom deflection angle. A stop watch and tape measure is useful to measure the current velocity accurately using floating debris.

H. Computer Aided Tools

As discussed earlier, many oil spill drift models can help with the planning process, especially for fast water responses. Computer programs are also used to track resources during a spill and handle logistics requirements. Strategies, boom placement locations and equipment requirements can be integrated into some models to assist with managing field deployments. The University of New Hampshire has developed a computer program to compute forces on booms in various configurations. Portable computers can be brought into the field to use as required.

8. INTEGRATION OF TECHNOLOGIES

Many types of technologies and strategies have been presented and discussed. Each has its advantages and liabilities. Selection and integration of the best components are required by the spill planner and responder to be effective in the fast water scenario presented. Several integration ideas are presented for fast water response.

A. Diversion Systems for In-line Skimmers

Some manufacturers sell high-speed skimmers with little attention to the requirements for an integrated sweep system in the current and wave conditions specified by the user. Oil deflection booms cannot be attached to the front of a high-speed skimmer and be expected to function well without some design considerations. The high forces on the boom will usually cause it to deform into a "J" or U-shape and result in oil entrainment when water velocities exceed one knot. Cross-bridles, a bottom support net or external tension boom is required to keep the boom at a proper diversion angle without deformation. Most deflection systems have too much draft adding high forces to the rigging and distorting the boom shape. Deflection boom used in protected water should not have more than 6-inch draft to reduce forces and keep its desired shape. Short rigid deflection boom arms angled in front of a skimmer can be effective but they cause more wave reflection than conventional flexible boom. Alternate methods of oil concentration should also be considered for high-speed skimmers that will not cause wave turbulence or oil entrainment at the mouth of the skimmer. Wave reflections cause higher short crested waves in the apex of a boom and decrease the recovery efficiency of the attached skimmer. V-shaped boom with an open apex can be towed in front of and separate from an independently powered skimmer trailing behind. The oil is concentrated into rows for easier pickup without the liability of amplified waves and turbulence at the mouth of the skimmer. This can also be accomplished by using oil flow diverters towed off both sides of a lead vessel heading into the current. The flow diverters change the direction of the surface current, thus transporting the oil into the wake of the leading vessel. This allows for a higher oil encounter rate for a skimmer following behind to collect. Water and air jets can also be suspended in front of a skimmer at the desired angle to concentrate the oil as it enters without the detrimental effects of wave reflection and amplification typically created from deflection boom. This method will be most effective when pitch motion of the skimmer is low so that the leading outriggers stay at an optimum height above the water.

B. Effective Use of Equipment and Strategies

Oil spill response on fast water is extremely difficult and demanding. To be effective in this environment, knowledge of the waterbody, its currents, natural collection points and available resources is essential. Fast water response is a process where success is measured by the ability to manage the flow direction of oil and to efficiently collect the most you can as it moves quickly down the river or coast. Controlling oil on fast moving water is difficult; you develop a plan, implement it that best you can. Frequently you have to modify strategies as conditions change.

Several techniques can be integrated to accomplish an objective. Boom deflectors can be used to supplement or replace shoreline ropes when using long boom lengths to deflect oil to shore. They can also work with the current rudder system replacing shoreline ropes to reduce forces on the rudders. Deflectors used with the current rudder will also simplify the deployment and retrieval of the boom to allow for ship passage. Flow diverters can be used in high currents and in shallow water to deflect oil to a low-velocity collection point where conventional deflection boom and skimmers can be effectively used. Sorbent material can be broadcast onto turbulent waters and collected downstream with deflection boom and a fixed sorbent/oil recovery system where currents are more manageable. Alternative techniques and strategies are only limited by your knowledge of the local conditions, available equipment and your imagination. Recommended strategies for the scenarios discussed in this report are presented in Table 2.

Table 2. Fast Current Scenarios and Strategies

Scenario	Amplifying Information	Strategies
Fast Current Navigable River	Keep vessel traffic flowing, such as on the Mississippi & Columbia River Systems and New York Harbor.	Open chevron or cascading booms with large gaps or partial river coverage to allow vessel passage.
No Tides	Account for wide & narrow rivers in inland areas such as the Mississippi, Ohio, Arkansas and St. Claire Rivers.	Narrow rivers: Current Rudder Wide river: Boom Deflectors or Encircle oil and divert to slow current
Reversing Tides	Account for trapping oil on reversing currents such as the Piscataqua, Hudson, Housatonic and Columbia Rivers and Cape Cod Canal.	Protect inlets on flood tides and trap oil on ebb tide or deploy deflection boom in the opposite direction on tidal changes.
Coastal High Tidal Currents	Account for longshore and tidal currents in areas like Mare Island and Clarence Straits.	Contain and recover oil offshore if possible and deflect to shore were access is available for recovery.
Harbor Entrance	Use deflection and containment options to prevent an ocean oil spill from entering for harbors such as Corpus Christi, Galveston, Wilmington and San Francisco Bays	Contain and recover oil offshore using offshore boom, VOSS and self-propelled skimmers. Deflect oil around harbor entrance. Also provide containment and deflection strategies in the harbor.
Moderate Waves and Wind	Open Bays and Coastal Areas such as Long Island Sound and San Francisco.	Use higher reserve buoyancy boom but keep draft to one foot or less.
Barrier Island Breachway Tidal Inlet	Contain oil before and after entering the breachway. Deflection and containment in the high current inlet is too difficult. The Carolinas, Texas and Rhode Island	Shoreline deflection before entrance. Sensitive area protection in tidal inlet using shore seal boom on tidal flats and deflection booming to access points for removal.
Large Open Bay with Reversing Tidal Currents	Similar to Delaware Bay and rivers.	Use pre-staged boom and skimmers to respond quickly to protect inlets.
Protect wetlands and river mouths on flood tide	Deflection strategies around the mouth of inlets and containment along shorelines with access.	Exclude oil with cascade boom at shallow angles past openings. Deflect to shore for containment.
Contain and Recover Oil in the Open Bay.	Concentrate oil with boom and skim it in open areas before it moves near sensitive wetlands.	VOSS, Self-propelled skimmers, V-shaped boom and shallow draft harbor boom.
Shallow Narrow River/Culvert (non-navigable)	Shallow rivers and culverts near pipelines, storage tanks and highways etc. Prudhoe Bay, AK and Bellingham, WA.	Water jets, air jets and flow diverters to divert oil flow to containment areas. Use of berm & underflow dams on low-volume outflow inlets.

9. TECHNOLOGY ASSESSMENT

A. ASTM Workshop

A preliminary assessment of available technology was presented to spill equipment users and manufacturers during an American Society of Testing and Materials (ASTM) committee workshop to solicit and incorporate their input. This two hour long workshop was presented to 30 participants on 25 March 1998. It was conducted in cooperation with the F-20 committee on Hazardous Substances and Oil Spill Response. Some new technologies were identified and others were discussed with people that had been present during testing. This process was used to verify and update technology ratings present below.

B. Technology Ratings

Booming strategies, specialized boom, alternate containment methods and high-speed skimmers are rated in several categories and presented in Table 3. This is a general summary of their capabilities as discussed throughout the report. The rating process is based upon independent data, manufacturers information, experience and engineering estimates. Technology names in Table 3 identified with an asterisk indicate that ratings are less reliable because data from controlled tests with oil were not available for them. Although data was used to determine the ratings whenever possible, rating determinations were made by the author in somewhat of a subjective manner for categories of: ease of deployment, effectiveness in debris/ice and effectiveness in shallow water. All category ratings however, were reviewed, discussed and in some cases revised based on input provided by participants at the ASTM F-20 committee meeting workshop as discussed above. Direct comparison between individual technologies is not recommended due to the variability in the test conditions.

1. Highest Effective Speed

The highest effective speed rating assumes that the equipment being rated is used by people who have been trained and are experienced in fast water response with that technology. The speed in knots represents the highest practical current or speed of advance, as applicable, that the technology can still effectively deflect, contain or skim oil from the water. Calm water conditions are assumed. Effectiveness will generally be diminished at the higher velocities, however, the majority of the oil (more than 50 percent) encountering the device will be controlled or recovered as desired at that upper limit speed rating.

2. Effective in Waves

Effectiveness in waves is dependent upon the oil recovery rate and oil recovery efficiency or deflection/containment capability in those conditions. Generally, a technology that has good reserve buoyancy, adequate freeboard and draft or can be decoupled from the influences of waves, will continue to be effective in waves. Short crested waves usually degrade the performance of equipment more than large long-period swells. A low (L) rating represents effectiveness in calm water conditions up to one-foot short crested waves. A medium (M) rating indicates effectiveness in short crested waves between 1 and 3-feet high, while a high (H) rating represents satisfactory performance in waves 3 to 6-feet high. Effectiveness in these conditions means that the technology will contain or collect the majority of oil it encounters.

3. Effective in Debris/Ice

Floating debris will cause problems with equipment by damaging it, moving it or rendering it ineffective. Some equipment is less affected by debris and floating ice due to its robust nature or method of containment/recovery. Some skimmers use debris screens that protect the pump but often require manual tending to remove the debris. A high (H) rating means that it will continue to function well in floating debris and ice with minimal manual tending required. Medium (M) rating represents a degraded performance level in debris while a low (L) rating indicates serious problems with performance in debris and both M and L ratings require significant manual tending to remove debris.

4. Effective in Shallow Water

Effectiveness in shallow water indicates the technology has a low or no draft requirement and that it will effectively contain, deflect or remove oil as designed. A yes (Y) indicates that a skimmer or boom system is manufactured that is effective in 2-feet deep water or it is not limited by a water depth of two feet. It is possible that some skimmers or boom systems receiving a no (N) rating could be produced by the manufacturer to function in shallow water if requested by a customer.

5. Ease of Deployment

The ease of deployment rating reflects the amount of complexity, training required, people and logistics involved to deploy and use the technology successfully. The more resources and training required to deploy the technology and use it effectively, the lower the rating. The faster a technology can be deployed with a minimum number of people and support equipment, the higher the rating. Generally, technology with good (G) and very good (VG) ease of deployment rating will continue to be effective close to the highest effective speed rating when using inexperienced personnel.

6. Oil Viscosity Range

Skimmers with reasonable oil recovery rates and recovery efficiencies of at least 50 percent in the viscosity range indicated were given the appropriate rating for that viscosity range. If a viscosity range is not listed for a skimmer then it is not effective at recovering oil in that viscosity range. A low (L) rating indicates that a skimmer is effective in light oil with a viscosity between 1 and 100 cSt. Medium (M) indicates effectiveness in medium grade oils with a viscosity between 100 and 1,000 cSt while high (H) means the skimmer was effective at recovering heavy oil with a viscosity between 1,000 and 60,000 cSt.

7. Oil Recovery Efficiency and Oil Recovery Rate

Skimmer specific performance ratings are based upon independent performance test data when available and manufacturer claims along with engineering principals used when data was not available. Generally, oil recovery efficiency will decrease and oil recovery rate will increase with speed. Technologies with the higher efficiencies and recovery rates that were not significantly degraded by increases in speed were given higher ratings. Skimmers with comparatively lower efficiencies and recovery rates that degraded quickly at faster speeds were given lower ratings. For details on skimmer performance, see discussions in the High-Speed Oil Skimmers section and cited references. Skimmers that demonstrated a poor (P) performance for recovery efficiency and/or oil recovery rate in currents above one knot were not included in this report and table.

Table 3. Technology Assessment of Strategies and Equipment

Technology Ratings For Oil Containment and Recovery Systems In High Speed Currents (1-6 knots)

Technology Name	Highest Effective Speed (kts.)	Effective in Waves[1]	Effective in Debris/Ice	Effective in Shallow[2]	Ease of Deployment	Skimmer Specific Performance: Oil Viscosity Range[3]	Skimmer Specific Performance: Oil Recovery Efficiency[4]	Skimmer Specific Performance: Oil Recovery Rate[5]	Comments:
Booming Strategies									
Cascade (DOWCAR Environmental)*	4	L	M	Y	F				Short sections independently moored to shore.
Deflection (Trans Mount. Pipeline)*	4	L	M	Y	F/G				Longer sections with shore tiebacks downstream.
Chevron (closed)*	3	M	M	Y	G				Quick to deploy because it uses fewer anchor points.
Chevron (open)*	3	M	M	Y	G				Allows for vessel traffic between openings.
Current Rudder (Blomberg Offshore)*	3	M	H	N	F				Allows for vessel traffic by control of rudder from shore.
Double Boom*	3	M	H	Y	F				Improved containment but hard to keep separated properly.
Boom Deflectors (Envirotech Nisku)*	4	M	M	Y	G				Deflectors used to keep boom at an angle without anchors.
Boom (Specialized)									
Fast Sweep (V-Shaped)	1.5	H	L	N	G				Net across foot of boom keeps it in a V-shape
Rapid Current Boom (UNH)	2.5	L	L	N	P				Incline plane, fabric bottom with outlet holes in pocket.
Horizontal Oil Boom	2.5	M	L	N	F				Two booms connected by net & filter fabric.
Holes in lower draft*	2	M	L	N	G				Larger draft with relief holes in lower skirt to reduce drag.
Net in foot of boom (NOFI)	1.3	H	L	N	G				Short vertical net at foot of the boom.
Foam 6 X 6, two tension lines*	4	L	L	Y	VG				Typical fast water diversion boom with upper & lower tension.
External Tension Line foam	2	M	L	N	F				High stability, limited reserve buoyancy
Shell High Current "Boom"	3	L	M	Y	P				Rigid aluminum perforated incline plane structure, diversion sys.
Alternate Methods									
Pneumatic Boom	1.5	M	H	N	G				High power required (30 hp/ft)
Water Jet (Horizontal)	3.5	M	M	Y	F				Reasonable power requirements (3 hp/ft)
Water Jet (Plunging)	4	M	M	N	F				Reasonable power requirements
Air Jet	3	M	M	Y	F				Low power required (1 hp/ft)
Flow Diverters (paravanes)	6	H	M	Y	VG				No power, changes surface currents to direction of anchor point.
Floating Paddlewheel	3	M	M	Y	G				Low power required (0.25 hp/ft), high-energy transfer.
Earth Dam (underflow)*	2	M	M	Y	P				Barrier blocking low flow into an inlet or out of a stream.

Technology Name	Highest Effective Speed (kts.)	Effective In Waves[1]	Effective In Debris/Ice	Effective In Shallow[2]	Ease of Deployment	Skimmer Specific Performance: Oil Viscosity Range[3]	Oil Recovery Efficiency[4]	Oil Recovery Rate[5]	Comments:
Skimmers									
Incline Skimmers									
Dynamic (JBF)	3	M/H	M	Y	G	L,M,H	G	G	VOSS & self propelled versions.
Static (Hyde Products)	5	M/H	M	N	G	L,M,H	G	G	VOSS, low maintenance
ZRV Skimmer									
Rope Mop (Ro-Clean Desmi)	5	H	H	N	G	L,M,H	VG	F	VOSS & self propelled catamarans
Sorbent Belt (USCG)	6	M	M	N	G	L,M,H	VG	F	Very high maintenance but effective
Quiescent Zone									
Expansion Weir (Vikoma)*	3	L	L	Y	G	L,M	F	G	Expansion slows flow
Circulation Weir (Blomberg Circus)*	3	M	L	Y	G	L,M,H	G	G	VOSS, portable lagoon
Brush Conveyor (Lori)	3	M/H	M/H	N	G	M,H	VG	F	VOSS, barge & self-propelled
Streaming Fiber & Belt (USCG)	3	M	L	N	G	L,M	G	F	Fibers slow flow, belt & weir remove oil
Lifting Belt									
Filter Belt (Marco)	3.5	M/H	M/H	Y	G	M,H	VG	F	Self-propelled & induction impeller
Rotating Disk Brush									
Rotating Brushes (Lamor)	3	M/H	M/H	Y	G	M,H	VG	G	VOSS, barge & self-propelled
Surface Slicing									
High Current Oil Boom	6	L	L	N	G	L,M,H	F	G	Weir with foil bow
Multi-purpose Oil Skimmer Sys.	3	M/H	L	N	G	L,M,H	F	G	Wave following weir
Russian Debris Skimmer	3	L	M/H	N	G	L,M,H	G	G	Debris filter, weir and gravity separator tank.
Trailing Adsorption									
Trailing Rope Mop (Force 7)*	4	H	H	N	F	L,M,H	VG	F	Batch processing requires retrieval of rope mops and paravane.
Free Floating Sorbent*	5	H	H	Y	G	L,M,H	VG	F	Free drifting sorbents and recover them downstream

Legend	H	High	Y	Yes	VG	Very Good
	M	Medium	N	No	G	Good
	L	Low			F	Fair
					P	Poor

Notes:

1. Low is effective in calm water to 1 foot waves, Medium is effective in 1 to 3 foot waves and High is effective in 3 to 6 foot waves
2. Yes indicates that a skimmer or boom system is manufactured that is effective in 2 foot of (shallow) water.
3. Low indicates a skimmer is effective in light oil 1-100 cSt viscosity, Medium 100-1,000 cSt & High 1,000-60,000 cSt
4. Oil recovery efficiency is the percent of oil recovered compared to the total volume or oil and free water collected.
5. Oil recovery rate is the rate of oil collected which is a combination of recovery efficiency and throughput efficiency.

* Ratings were based on engineering principles, expert opinions & field experience but not in controlled test results with oil. Technology names with no asterisk were rated based upon data obtained from controlled tests with oil.

10. USCG Response Regulations

Vessel and facility response plan regulations and oil spill response organization (OSRO) classification guidelines were reviewed to determine if fast water oil spill control and recovery was adequately addressed. Marine Transportation-Related Facility Response Plan; Final Rules are published in 33 Code of Federal Register (CFR) Parts 150 and 154 dated February 29, 1996. Vessel Response Plans; Final Rule is published in 33 CFR Part 155 dated January 12, 1996. Guidelines for Classifying Oil Spill Removal Organizations, revised April 29, 1997 are listed on the USCG web site www.uscg.mil/hq/g-m/nmc/response/osro.htm.

The USCG rules and guidelines do not address any requirements specific to fast-water oil spill containment and recovery. In fact, the requirements for river and canal boom height (draft plus freeboard) is 6-18 inches. Boom with a draft over 6 inches; however, is not effective in high-speed currents due to the high drag forces. OSRO classification, facility and vessel response plans can be approved using 18-inch boom although it would be ineffective in currents above one knot. Fast current oil spill containment on inland, Great Lakes and ocean response also require shallow draft boom which according to the USCG requirements would not qualify because it would be too small. Skimmer requirements are based upon a generic 20 percent skimmer recovery efficiency and an effective daily recovery capacity; however, no considerations are placed on the use of skimmers or strategies optimized for fast current situations. Skimmers that are ineffective in high-speed currents could be acceptable for vessel and facility response plans in fast current regions based upon calm water and low current performance. OSRO classification guidelines do allow for the COTP to grant waivers to use boom other than the recommended "best suited" in an environment relative the unique local conditions such as currents, tides, water depth, etc. Training requirements for rules and guidelines are vague and cursory concerning equipment response and do not address fast-water response considerations.

11. Decision Guide

Threats, scenarios, strategies and equipment for fast-water oil spills have been discussed in detail. A decision guide for coastal and inland waters was developed for oil spill response in different environmental conditions for Environment Canada.[56] This guide has been updated and revised to include the fast water oil spill technology presented in this investigation and they are provided in Table 4 and Table 5 below for coastal and inland waters respectively.

A. Coastal

Table 4. Decision Guide for Coastal Oil Spill Response

Configuration of Area to Be Protected	Question	Answer	Water Current Speed	Response
Straight coastline with sensitive areas	Are breaking waves 1.5 ft present in area where boom will be deployed?	YES		Beach berm or containment booming of slick outside of surf zone
		NO		Diversion booming upstream of sensitive area
Entrance to bays, harbors, lagoons, etc.	Are breaking waves 1.5 ft present in the area where boom will be deployed?	NO	Less than 1 kt	Exclusion booming across entrance
			Greater than 1 kt	Diversion booming at an angle in entrance or inside of entrance where water currents diminish
		YES: Can booming location be moved to calmer area?		
	Can booming location be moved to calmer area?	YES	Less than 1 kt	Exclusion booming across entrance
			Greater than 1 kt	Diversion booming at an angle in entrance or inside of entrance where water currents diminish
		NO		Containment booming of slick outside of entrance
Narrow tidal channel			Less than 1 kt	Exclusion booming across entrance or Sorbent barrier across entrance (if minor sheen)
			Greater than 1 kt	Diversion booming at an angle across channel

B. Inland Waters

Table 5. Decision Guide for Inland Waters Oil Spill Response

Type of Water Body			
Large Lake with water currents and waves	Use Table 4 for Coastal Water Protection		
Lake or Pond	Amount of Oil Contamination	Minor sheen	Sorbent booming
		Moderate to major visible slick	Containment booming
Rivers or large streams (greater than 2 feet deep)	Water Current Speed	Less than 1 kt	Containment or exclusion booming
		Between 1 & 2 kt	Single diversion boom
		Greater than 2 kt	- Cascading diversion booms - Oil flow diverters - Encircle with boom & divert. - Single diversion boom using: shoreline ties or boom deflectors - Current rudder with boom - High speed skimmers
Small streams (less than 10 meters wide & more than 2 feet deep)	Water Current Speed	Less than 1 kt	Sorbent barrier or containment booming
		Between 1 & 2 kt	Single diversion boom
		Greater than 2 kt*	- Cascading diversion booms - Single diversion boom using shoreline ties or boom deflectors - High speed skimmers
Shallow rivers or streams less than 2 feet deep	Berm or underflow dam across the stream bed		

* If current speed exceeds 3 knots, booming should be attempted at an alternate location where currents are lower.

12. TRAINING

A. USCG

The US Coast Guard does not conduct in-house fast-water oil spill response training for the three Strike Teams. It relies on industry training courses that do not cover all aspects of the technology comprehensively. Each Strike Team member is required to attend either the DOWCAR Environmental, Inland Waters Oil Spill Response Course or the Texas A&M Galveston, Oil Spill Control Course. The DOWCAR course addresses fast water response, while the Texas A&M course does not. Two other Texas A&M Galveston courses listed in Table 6 are more applicable to fast water response. The Corpus Christi course emphasized hazardous material response and safety.

Industry training is expensive when travel and per diem costs are added to class fees. They can run a total of $2,500 per person depending upon travel costs. It appears to be more economical to run courses at USCG units with in-house instructors and USCG equipment. This would require that the Strike Teams purchase some fast water shallow draft boom and other equipment for training purposes. Once a detailed training plan is formulated, a cost analysis should be developed before a final decision is made.

Each spill responder also learns by on-the-job training while completing their various levels of qualifications using their existing inventory of equipment. This inventory does not include any fast water boom and only one type of High Speed Skimmer and sweep system designed for coastal and offshore use. Reliance on industry training and on-the-job training for National Strike Force personnel is inadequate to obtain an in-depth knowledge of technology and strategies applicable to fast water oil containment and recovery. COTP and MSO personnel also need more comprehensive training in order to conduct effective reviews of response plans, inspect OSRP classifications, and supervise spill response operations in fast water regions.

B. Industry

Four industry training courses were reviewed from three sources. Although these courses teach various strategies and technologies for containment and removal of oil in currents, they do not thoroughly address the subject due to the broad nature of the courses and limited knowledge of the subject. In some cases, one strategy is taught well but other strategies are glossed over or not presented. The courses reviewed are listed in Table 6 in order of effectiveness. More curriculum details of these courses are provided in Appendix O.

Table 6. Industry Oil Spill Training Courses for Fast Water Oil Spill Response

Course Title & Location	Tuition	Length	Field / Classroom (hours)
Inland Waters Oil Spill Response DOWCAR Environmental Management Inc. Taos, New Mexico	$995	50 hours/ 5 days	29 / 21
Freshwater Oil Spill Control Center for Marine Training and Safety Texas A&M University, Galveston, Texas	$975	40 hours/ 5 days	20 / 20
Freshwater Oil Spill Refresher Center for Marine Training and Safety Texas A&M University, Galveston, Texas	$650	24 hours/ 3 days	18 / 6
Inland Oil Spill Response and Safety National Spill Control School Texas A&M University, Corpus Christi, Texas	$795	40 hours/ 5 days	24 / 16

13. CONCLUSIONS

A. Fast Water Oil Spill Threats are Significant

Fifty eight percent of all oil spills that were identifiable by location over the past six years (4,519,749 gallons) occurred on waterways where the current routinely exceeded one knot. Oil transported annually on all US waterbodies and ports is 931 million tons. Oil transported on waterbodies and ports with currents that routinely exceed one knot totals 645 million tons annually representing 69 percent of all oil transported. There are thousands of facilities on waterways throughout the US capable of spilling oil into fast waterways. The average worst-case discharge threat of a representative sample was 6.3 million gallons per facility.

B. Benefits of Fast Water Oil Spill Containment and Recovery

Spills in currents that exceed one knot will be transported more quickly and contact more shoreline than spills in quiet waters. This poses a more extensive threat to a greater number of sensitive areas along the coast compared to low current situations. The oil spill processes of dispersion, advection, dissolution, emulsification and sedimentation are accelerated in fast turbulent waters. Quick response is imperative since delays in containment make it more likely that oil will mix in the water column, grow in volume due to emulsification and possibly sink to the bottom due to sedimentation. This fast water oil mixing process greatly increases the cleanup costs and impacts the environment in three regions: on the surface, in the water column and on the bottom. The potential for more severe environmental damage and the contamination of drinking and industrial water intakes are more likely in fast water conditions. Cleanup costs and environmental damage will be significantly reduced through the effective use of oil containment and recovery methods and equipment optimized for fast water conditions.

C. Fast Water Technology Development

Significant research and development was conducted in the 1970s and early 1980s; however, very little has been done to improve the state-of-the-art in the past ten years. Very often promising technologies were developed and tested by Government agencies and the oil industry but rarely made it to production. Generally, oil spill equipment manufacturers are small businesses that cannot sustain an R&D effort for new product development. Typically, only incremental improvements are made to existing boom and skimmer products. There was a small increase of research due to the OPA-90 legislation in the early 1990's however, very little of that money was devoted to mechanical recovery devices or methods. Only a small portion of mechanical recovery research funding has been devoted to improving fast water oil containment and recovery technology.

D. Present Capabilities are Effective but Limited

The capabilities outlined in this report can be effective in currents between 1 and 3 knots if properly applied with trained personnel. The effectiveness can be increased if the current and shoreline characteristics are used to enhance deployment and containment performance. A few techniques show promise up to 6 knots. The response methods effective in current above 3 knots often use dedicated high speed skimming vessels that are expensive to purchase, operate and maintain. The USCG ZRV skimmer was one of the most effective fast-water/high-speed skimmers tested but it was never commercially developed.

E. Fast Water Training Technology is Limited and Dispersed

USCG Strike Teams and MSO personnel need to know how to use and apply fast water oil spill response technology for oil spill management, response and approval of facility and vessel response plans. The Coast Guard does not conduct fast-water oil spill response in-house training. It relies on industry training. The industry training available, however, does not thoroughly address fast water response due to the broad nature of the courses and in some cases limited knowledge of the subject.

F. USCG Regulations and Guidelines Ignore Fast Water Considerations

The rules do not address any requirements specific to fast-water oil spill containment and recovery. Fast water is not even listed as a factor that can degrade response capabilities. This allows for booms and skimmers to be accepted for facility and vessel response plans and OSRO classification, although they are in some cases ineffective in local high-speed current environments. Industry training requirements are vague and cursory concerning equipment response and do not address fast-water response considerations.

14. RECOMMENDATIONS

There is a need to develop and test promising fast water oil spill equipment and strategies. Field demonstrations are recommended to perfect the technology and concepts in real world scenarios. A technology transfer program needs to be formalized so that Government sponsored research on spill response equipment and strategies are made available to the public in a form that is can easily be commercially developed and used. Training should be developed that comprehensively addresses control, containment and recovery of oil spills in fast currents. USCG regulations and guidelines concerning response plans and OSRO classifications should be revised to address response resources that are limited by currents above one knot and fast-water scenarios that require special strategies, equipment and training.

A. Technology Development

Promising technology has been identified that require further development through analytical analysis, test tank verification and field-testing. Several fast-water skimmers on the market have not been tested in controlled conditions with oil. These promising systems should be tested at OHMSETT or at spills-of-opportunity to determine their capabilities and limitations. Of particular interest are the Blomberg Circus quiescent zone skimmer, the Vikoma Fasflo expanding weir skimmer and the Ro-Clean Desmi Pollcat rope mop ZRV skimmer.

The recently procured USCG High Speed Skimmer can recover oil in deep water fast currents. Tests in OHMSET show that the High Speed Skimmer with the Fast Sweep™ deflection boom attached starts to loose effectiveness at 3 knots. Alternative diversion systems should be investigated and developed to facilitate more efficient use of this skimmer in currents up to 5 knots.

Paravane Flow Diverters were tested in a circulation water channel and on the Saint Lawrence River in the mid-1970s. They showed promise to divert oil in high-speed currents by changing the direction of the surface currents. This method should be further developed and tested for use where booms cannot be deployed. The effectiveness of smaller more lightweight paravanes should be investigated. It also shows promise for concentrating oil into narrow windrows when deployed from both sides of a vessel for pickup by a trailing skimmer.

B. Field Demonstrations

Field demonstrations are recommended for developing technologies to investigate their capabilities and limitations in real world scenarios. They can be conducted as dedicated demonstrations or integrated into ongoing exercises, drills, or spills-of-opportunity.

The University of New Hampshire (UNH) Rapid Current Boom has been developed and tested over the past several years with funding assistance from the USCG and the US Minerals Management Service (MMS). It uses inclined plane technology and is effective in currents up to 2.5 knots. Field demonstrations are recommended to gain more insight into the application of this containment system. A larger reserve buoyancy boom and V-shape apex should be investigated to increase performance at higher speeds.

The Blomberg current rudder consisting of three paravanes mounted in a frame, uses hydrodynamic forces of the current to deploy and retrieve deflection containment boom from shore. Movement is controlled with lines to the current rudder that change the paravanes' angle of attack to the flowing water. The advantage of this system is that only one person using a winch can retrieve deployed boom to shore. This allows vessel traffic on a river to pass. The boom is then deployed again back across the river in the opposite manner. This technology can also be used to deploy a containment boom sweep from a vessel without the use of heavy outriggers. Demonstration of the river booming strategy is recommended for the Columbia River System. Demonstration of the vessel of opportunity skimming system is recommended for a USCG VOSS exercise using the Fast-Sweep™ and Flexi-Boom ™ configurations.

Boom deflectors are devices that use the hydrodynamic flow of water on the backside of the boom to push and hold the boom at an angle to the current. They are attached to short boom sections at each connection point. The benefit is that long lengths of boom can be quickly deployed in a deflection mode without the use of multiple anchors or

shore-side lines. This is most useful in wide fast flowing rivers such as the Mississippi. The concept was initially demonstrated in the 1970s and recently improved upon by a Canadian company. It also may be effective as a diversionary concentration system for large V-shape boom towed from two vessels without the use of cross bridles. Cross bridles are difficult to rig easily snagging on the bottom. Boom deflectors may also work well with the current rudder by keeping the deflection boom angled into the current without the use of shore-side lines that tend to catch debris and may put too much tension of the boom. Demonstrations of the Envirotech boom deflectors are recommended in those configurations for the Mississippi River or a fast-flow bay such as the San Francisco or Delaware Bays.

C. Training Initiatives

COTPs and MSOs have responsibility for approving vessel and facility response plans and classifying OSROs as well as granting equipment waivers. The NSF and MSOs have the responsibility for responding to and managing response efforts in fast-water oil spill conditions. They, however, do not have any training or guides that enable them to make informed decisions under the rigorous requirements for fast water conditions. Development of a field-guide for use in fast-water oil spill response is recommended for the NSF, MSOs and COTPs.

There are no commercial or USCG in-house training courses currently available that provide a comprehensive coverage of fast water oil spill control and recovery technologies and strategies. Several training initiatives are recommended for the USCG. Development of an in-house fast-water oil spill control and recovery training course is recommended for the USCG National Strike Force (NSF). This should be conducted at a lead Strike Team or District Response Advisory Team (DRAT). Multi-Media training aids such as a training video and computer-based training should be developed to facilitate field training. A Power Point™ animated slide show may also be effective to facilitate the in-house classroom portion of the training program. These aids can also supplement training at COTPs and DRATs. The training course should also include extensive field exercises in control and recovery of oil on fast-water rivers or bays. Four new civilian oil spill equipment specialists billets should be established for the NSF. One billet is recommended for each of the three Strike Teams and one for the Coordination Center. They will facilitate training and perpetuate an oil spill equipment capabilities expertise that is lost each year when approximately one third of the military personnel are transferred at those commands. A second civilian billet could also provide longevity to the three Teams and Coordination Center on equipment and training needs in the hazardous materials response and safety arena.

D. USCG Regulation and Guideline Improvements

The rules do not address any requirements specific to fast-water oil spill containment and recovery. The CFR regulations for facility and vessel oil spill response plans and OSRO classification guidelines should be revised to improve the requirements for spill response and training in currents above one knot. Limitations on equipment in high-speed current scenarios should be required in the planning process when applicable.

E. Incentives

A significant quantity of information and research are available concerning fast water oil spill technology, but most of it is outdated. There is much more that needs to be done to develop new technologies, strategies and training methods. However, there are no incentives in the oil spill industry encouraging efficiency. In fact, it is well known by response contractors that the longer it takes to clean up a spill the more money they will make. Customers want low rates for response services and response organizations want to remain competitive. Response organizations therefore often strive to meet the minimum requirements set forth by the regulatory agencies. These regulations do not even addresses the limitations of response equipment in currents over one knot.

Manufacturers of foam boom operate on a very slim profit margin and there is a limited market for oil skimmers, especially fast-water skimmers, so there is little incentive for research and new product development. Unfortunately, the research funded by OPA-90 legislation was short-lived. The oil spill response industry expanded in the early 1990s in response to the OPA-90 requirements and has recently completed purchasing their equipment inventories. Therefore, there is no incentive for manufacturers to spend money to research innovative technologies and there is no incentive for responders to purchase and use them once developed. If there were profit motives and incentives for spill responders to be more efficient, demand for better equipment would increase. Without a change of philosophy toward efficiency in response to oil spills by government regulators, the oil industry and the insurance underwriters, new fast-water oil spill technology and other oil spill response innovations will continue to be stifled.

REFERENCES

1 Exxon Oil Spill Response Field Manual, Exxon Production Research Co., 1992, pp. 13,15, 16, 49, 51 & 52.

2 Oil Spill Prevention & Control Course Book, National Spill Control School, Texas A&M, Corpus Christi, TX 1991, pp. E-6, Sc-1 & Sc-2.

3 Anderson, Eric, Mendelsohn, Daniel, and Howlett, Eoin. "The OILMAPWin/WOSM Oil Spill Model: Application to Hindcast a River Spill," Proceedings of the 18th Arctic and Marine Oilspill Program Technical Seminar, Applied Science Associates, Inc., 1995, p 801.

4 Agrawal, Ram K., and Hale, L. A. "A New Criterion for Predicting Headwave Instability of an Oil Slick Retained by a Barrier," Offshore Technology Conference, OTC 1983, Heat Research Corp., 1974.

5 Marine Safety and Marine Environmental Protection Business Plan Performance Report 1996 (Preliminary Report), USCG Marine Safety and Environmental Protection Division, pp. Enclosure (3) p. 15 and Appendix III.

6 Reed's Nautical Almanac North America (West Coast 1998) and (East Coast 1998), Editor Ben Ellison, Thomas Reed Publications, Inc., Boston, MA, 1998.

7 Forrest, Robert, Lopez, David, and Peckham, Richard. "A Major Oil Barge Pollution Incident on the Arkansas River," 1985 Oil Spill Conference Proceedings, US EPA, Emergency Response Branch (GES-E), 1985.

8 Nordvik, Atle B., Sloan, Stacey, and Stahovec, Joe. "Phase 3: Oil Containment Boom At Sea Performance Tests," 95-003, MSRC R&D and others, 1995.

9 Paskewich, LCDR James T., and Thompson, Lt. Edmond P. "Oceanographic Surveys of Tidal Inlets for Oil Spill Response," 1981 Proceedings of Oil Spill Conference, USCG Gulf Strike Team, 1981.

10 Hayes, Miles O., and Montello, Todd. "The Development of Potential Protection Strategies for Tidal Inlets," 1995 International Oil Spill Conference, Research Planning, Inc., 1995.

11 Park, William C. "Response to the Mobil Oil Spill, 1985 Oil Spill Conference Proceedings," Mobil Oil Corporation, 1985.

12 Hancock, J. A., Jacobs, R. P., and Knapp, M. R. "Waterborne Debris in Marine Pollution Incidents," Columbus Laboratories, 1974.

13 Tsang, Dr. G., Vanderkooy, N. "An Ice-Oil Boom - From Tsang's Folly to Tsang's Boom," Spill Technology Newsletter, Vol. 3, March-April, Canada Centre for Inland Waters, 1978.

14 Allen, Alan A. "Containment and Recovery Techniques for Cold Weather, Inland Oil Spills," 1979 Oil Spill Conference, Crowley Environmental Services , Alaska, 1979.

15 Telford, A. S., and Quam, H. A. "Oil Recovery from Under River Ice, 1979 Oil Spill Conference," Esso Resources Canada Ltd., 1979.

16 US Navy Ship Salvage Manual Volume 6 (Oil Spill Response), 1 December 1991, p. E-3

17 Brodsky, L., Charles, M. E., and Greene, G. D. "The Use of Deflectors for the Deployment of Oil Booms at an Angle to River Currents," Pace Report no. 77-3, Dept. of Chemical Engr. and Applied Chemistry, 1977.

18 Wong, Kau-Fui Vincent, and Wolek, A. "Application of Flow Visualization to the Development of an Innovative Boom System," Proceedings of the 19th Arctic and Marine Oilspill Program Technical Seminar, College of Engineering, U. of Miami, 1996.

19 Fern, G.R.H. "The Oil Spill Countermeasures Activities of the Petroleum Association for Conservation of the Cana...," Spill Technology Newsletter, Vol. 2, July-August, National Coordinating Committee, 1977, pp. 30, 32.

20 Personal communications with Mervin Fingas, Ph.D., Chief, Emergencies Science Division Environmental Protection Service, Environment Canada, Ottawa, Ontario at the ASTM meeting in Memphis, TN, 25 March 1998.

21 Bitting, Kenneth, and Vicedomine, James. "NOFI Oil Vee-Sweep and Extension Boom Test at OHMSETT," Proceedings of the 16th Arctic Marine Oilspill Program Technical Seminar, US Coast Guard R&D Center, 1993.

22 Swift, M., Celikkol, Barbaros, Steen, Robert. "Development of a Rapid Current Containment Boom: Phase III," Jere Chase Ocean Engineering Center, 1998, p 43.

23 Ayers, R. R. "A Rigid, Perforated Plate Oil Boom," EPA-600/2/-76-263, Shell Development Co., 1976.

24 Fraser, John P., Clark, L. M. C. "SOCK Skimmer - Performance and Field Tests, Journal of Petroleum Technology," Shell Oil Co., 1984.

25 Williams, R.E., and Cooke, T.S. "Feasibility of Using a Bubble Barrier for the Containment/Incineration of Spilled Oil," Proceedings of the 8th Arctic Marine Oilspill Program Technical Seminar, Exxon Production Research Co., 1985, p 214.

26 "Air Bubble Diverter," Canadian Petroleum Association, 1980-0001, Canadian Petroleum Industry Research, 1980, p 6.

27 Laperriere, F., Whittaker, H., and Yanagisawa, M. "High Pressure Water Jet Testing for Oil Containment in Simulated Environmental Conditions," Proceedings of the 10th Arctic Marine Oilspill Program Technical Seminar, Environment Canada, 1987.

28 Comfort, G., Menon, B., and Noble, P. "Feasibility of Air and Water Spray Barriers for the Collection, Concentration and In-Situ Burning...," Proceedings of the Arctic Marine Oilspill Program Technical Seminar, Arctic Canada Ltd., 1979.

29 "Oil Spill Containment and Removal System: A Feasibility Study," 70-6787, Pacific Northwest Laboratories, 1970.

30 Nash, J. H., and Johnson, M.G. "Coherent, Plunging Water Jets for Oil Spill Control," 1981 Proceedings of Oil Spill Conference, Mason & Hanger-Silas Mason Co., Inc., 1981.

31 Farlow, John S., and Cunningham, John M. "Plunging Water Jets: Evaluating an Innovative High-Current Diversionary Boom," 1993 Oil Spill Conference Proceedings, Risk Reduction Engineering Laboratory, US EPA, 1993.

32 Freestone, Frank, Anderson, Reg, and Trentacoste, Nicholas. "US EPA Research in High-Speed Devices for the Recovery of Thin-Film Oil Spills," 1975 Conference on Prevention and Control of Oil Pollution, EPA and others, 1975.

33 Cohen, Steven H., Lindemuth, William T., and Farlow, John S. "Development and Tests of an Air-Jet Oil Boom," 1979 Oil Spill Conference, Hydronautics, Inc., 1979.

34 Eryuzlu, N.E., and Hausser, R. "Use of Floating Deflectors for Oil Spill Control in Fast Flowing Waters," 1977 Oil Spill Conference, Canadian Coast Guard, 1977, pp. 335-340.

Personal communication with Ken Bitting, USCG Research and Development Center, Avery Point, Groton, CT, concerning the Paddlewheel Boom Tests at OHMSETT, Feb. 1998.

36 Personal Communication with Edward Stanton, Commander, USCG, US Coast Guard Eighth Coast Guard District, New Orleans, LA, Concerning use of dispersants on high volume rivers, Feb. 1998.

37 Unpublished OHMSETT data from the USCG High Speed Skimmer acquisition evaluations (late 1996) provided by Hyde Products Inc., Cleveland, OH for the HIB-20 skimmer, March 1998.

38 Nadeau, P. F. "USN DIP 3001 Performance Test Program Summary Report," Naval Facilities Engineering Command, 1976.

39 Smith, Gary F., and Lichte, Henry W. "Summary of U.S. Environmental Protection Agency's OHMSETT Testing," 1974-1979, EPA-600/9-81-007, Mason & Hanger-Silas Mason Co., Inc., 1981, pp. 138-144.

40 BP Exploration Operating Terminal, Sullom Voe Terminal, Mossbank, Shetland, Letter documenting tests on the MV KYRRE rope mop ZRV skimmer, dated 19 June 1988.

41 Farlow, John S., and Griffiths, Richard A. "OHMSETT Research Overview, 1979-80," 1981 Proceedings of Oil Spill Conference, Municipal Environmental Research Lab, US EPA, 1981.

42 Breslin, Michael. "Performance Tests of High Speed ZRV Oil Skimmer," CG-D-42-80, Mason & Hanger-Silas Mason Co., Inc., 1980.

43 Blomberg, Erling, and Claeson, Claes Magnus. "Oil Spill Clean-up Technologies for Rivers, Ports and Sheltered Waters: Part I", Spill Science & Technology Bulletin, Vol. 4, No. 0, Erling Blomberg Offshore, 1997.

43 Urban, Robert, Graham, Douglas, and Schwartz, Sol. "Performance Tests of Four Selected Oil Spill Skimmers," EPA-600/2-78-204, Mason & Hanger-Silas Mason Co., Inc., 1978, pp 43-57.

44 Blomberg, Erling and Claeson, Claes Magnus. "Oil Spill Clean-up Technologies for Rivers, Ports and Sheltered Waters: Part I...," Spill Science & Technology Bulletin, Vol. 4, No. 0, Erling Blomberg Offshore, 1997.

45 Beach, R. L., and March, F. A. "Development of a Streaming-Fiber Oil Spill Control Concept," G-D-35-75, Seaward, Inc., 1975.

46 Mar, Inc., "OHMSETT Tests of Lori LSC-2 Skimmer Systems," USCG Research and Development Center, Avery Point, Groton, CT, USCG Report Number CG-D-17_94, November 1994.

47 Lichte, H. W., and Breslin, M. K. "Performance Testing of Three Offshore Skimming Devices," EPA-600/7-78-082, Mason &Hanger-Silas Mason Co., Inc, 1978.

48 Swedish Coast Guard Letter Dated 7/29/93 documenting tests conducted on the Lori and Lamor Side Collector Skimmers.

49 Folsom, Blair A. "Development of a High Current Oilboom/Skimmer," EPA-600/2-80-140, Ultrasystems, Inc., 1980.

50 Clauss, G. F., and Kuhnlein, W. L. "Efficiency of Selected Oil Skimming Systems in Irregular Seas," Proceedings 1991 International Oil Spill Conference, San Diego, CA, March 4-7, 1991, pp. 120 – 122.

51 Lichte, H. W. "Performance Testing of the Soviet Oil/Debris Skimmer," EPA-600/2-81-154, Mason & Hanger-Silas Mason Co., Inc., 1981.

52 "Force 7 Offshore Oil Recovery System Description Specification 7/185," Oil Pollution Environmental Control Ltd., West Yorkshire, UK

53 Shaw, Sidney H., and Dorrler, J. Stephen. "A Distributed Reusable-Sorbent Oil Recovery System," 1977 Oil Spill Conference, Seaward International, Inc., 1977.

54 Brown, H.M., Nicholson, P., and Goodman, R.H. "Novel Concepts for the Containment of Oil in Flowing Water," Proceedings of the 16th Artic Marine Oilspill Program Technical Seminar, Imperial Oil Ltd., Resources Division, 1993.

55 Dowell, George W. and Coudon, Tom. "MSRC Shuttle Barge System for Shallow-Water Oil Spill Cleanup," 1995 International Oil Spill Conference, Marine Spill Response Corporation, 1995.

56 "Canadian Inland Waters: Coastal Environments and the Cleanup of Oil Spills," Report EPS 3-EC-82-3, Environment Canada, 1982, pp 16-17.

57 Defant, Albert. "Ebb and Flow, The Tides of Earth, Wind, Air and Water," The University Press, Ann Arbor, MI, 1958, pp. 60-63.

58 Owens, Edward, and Michel Jacqueline. "Options for Minimizing Environmental Impacts of Freshwater Spill Response," API publication No. 4558, Woodward-Clyde Consultants, 1994.

59 Inland Waters Oil Spill Response Course material, DOWCAR Environmental Management Inc., Taos, New Mexico, 1997.

APPENDIX A Research Contacts

Table A-1. Organizations, Experts and Companies Contacted

Type of Organization	Organization/ Company Name	Main Individual/Position
Government	Canadian Coast Guard	John Latour & Web Page
	Environment Canada	Mervin Fingas & Library
	USACOE Commerce Transportation Statistics	Charlotte Cook
	USCG Headquarters (G-MIR)	Gary Chapel
	USCG Headquarters (G-MOR)	CDR Mark Johnson
		LT Tom Callahan
	USCG Atlantic Strike Team	CWO Tim Malcolm
		CWO Alex Alenitsch
	USCG Eighth District	CDR Ed Stanton
	USCG First District (DRAT)	John Deck
	USCG Gulf Strike Team	CDR Scott Hartley
	USCG Headquarters (G-SEC)	LCDR Chris Doane
	USCG MSOs & COTPs (all)	FRP Coordinators
	USCG National Strike Force Coordination Center	Christine Burke
		LT Teri Jordan
	USCG Ninth District (DRAT)	Bob Lallier
	USCG Pacific Strike Team	CWO Jim Crouse
	USCG Research & Development Center	Ken Bitting
	USCG Seventeenth District (DRAT)	Rick Janelle
	USCG Thirteenth District (DRAT)	Scott Knutson
	USEPA	Libraries & Web Sites
	USGS	Field Units and Web Sites
	USMMS OHMSETT	Library & Files
Industry	Alaska Clean Seas, Prudhoe Bay, AK	Nick Glover
	Alyeska Pipeline Services Corp., Anchorage, AK	Larry Shier
	American Boom & Barrier Corp., Cape Canaveral, FL	Sean Geary
	American Petroleum Institute (API)	Library & Web Page
	American Society of Testing and Materials (ASTM)	F-20 Committee Meeting
	Applied Fabrics Technologies, Inc., Orchard Park, NY	Peter Lane
	Blomberg Offshore AB, Frolunda, Sweden	Erling Blomberg
	Canadian Association of Petroleum Producers (CAPP)	Library & Web Page
	Canflex (USA) Inc., Anacortes, WA	Jim Vicedominin
	Clean Casco Bay, Portland, ME	John Ferland
	Clean Channel Association, Houston, TX	Raymond Meyers
	Clean Harbor, New York Cooperative	Manager
	Clean Rivers Cooperative, Portland, OR	Ray Richmond
	Delaware Bay and River Cooperative	Eugene Johnson
	DOWCAR Environmental Management, Inc., Taos, NM	Carl Oskins & Class Book
	Envirotech Nisku Inc., Alberta, Canada	Len Brown
	Exxon Research & Engineering Company	William Dahl
	Flemingco Inc, Sulsted, Denmark	Flemming Hvidbak
	Hyde Products, Inc., Cleveland, OH	Jim Mackey
	JBF Environmental Systems Inc., Ellsworth, ME	Ralph Bianci
	Kepner Plastics Fabricators, Inc., Torrance, CA	Frank Meyers
	Marco Pollution Control, Seattle, WA	Paul Smith

Table A-1. Organizations, Experts and Companies Contacted (continued)

Type of Organization	Organization/ Company Name	Main Individual/Position
Industry	Marine Pollution Control, Detroit, MI	Dave Usher
	Marine Spill Response Cooperation (MSRC) NJ	Robert Gellatly
	Oil Stop Inc., Harvey, LA	Rick Lazes
	PCCI, Alexandria, VA	Bob Urban
	Piscataqua River, Portsmouth, NH Cooperative	Paul Nevins
	QualiTech Environmental, Chaska, MN	Mark Ploen
	Ro Clean Desmi, Norfolk, VA	Stewart Ellis
	Trans Mountain Pipeline, Vancouver, BC	Ian Lambton
	Vikoma, Isle of Wright, UK	Sales Rep
	World Catalogue JV, Annapolis, MD	Robert Schulze
Universities	Johns Hopkins University, Baltimore, MD	Dr. John Katz
	Mass. Maritime Academy, Center for Marine Env. Prot.	Ed O'Brian
	Texas A&M, Galveston, TX, Oil Spill Control School	Craig Kartye
	Texas A&M, Corpus Christi, National Spill Control Sch	Roy Coons
	University of New Hampshire	Dr. Rob Swift

Appendix B Properties and Processes of Spilled Oil

Definition of Oil

Oil, for the purposes of oil spill response in this investigation, consists of petroleum hydrocarbons, animal fats and vegetable oils in liquid form that can be spilled on the surface of the water and cause subsequent environmental damage and economic loss. Petroleum hydrocarbons are the most commonly spilled oil. The chemical compounds in petroleum are mainly composed of carbon, hydrogen, oxygen, sulfur and nitrogen.[2] The compounds found in petroleum are classified into three major categories: saturates, aromatics and nitrogen sulfur or oxygen (NSO) compounds. Saturated hydrocarbons contain carbon and hydrogen atoms in straight or branched chains. Aromatic hydrocarbons are the lighter components that have a benzene ring and sometimes side chains attached. NSO compounds are generally heavier, darker and more viscous components. There are, however, over five hundred kinds of organic compounds that have been identified in petroleum that make each spill unique and their physical property changes with time sometimes difficult to predict.[2]

Properties of Oil

Surface Tension

Surface tension is related to the molecular forces between the molecules of a liquid. The oil molecules at the surface tend to have less attractive forces to the air above or water below and experience a net force inward. The oil-air surface tension plays a major role in the final spreading of oil. The oil-water surface tension is also very important, but for another mechanism: interfacial mixing. The higher the oil-water surface tension is the more resistant the oil is to forming interfacial waves and eventual mixing. Both the oil-air and oil-water surface tension tends to increase as weathering occurs slowing the final stages of oil spreading.

Specific Gravity

Specific gravity is the ratio of the weight of any substance per unit volume to the weight of an equal volume of fresh water at 4°C as a standard. The specific gravity of oil determines whether it will float or sink in water. Fresh water at 4° has a specific gravity of 1.00. Most oils have specific gravity between 0.85 and 0.95 and will float in water however; this property will generally increase with weathering and oil become less buoyant during a spill response. Seawater has a specific gravity of approximately 1.04, so oil will be more buoyant in seawater.

Viscosity

Viscosity describes the frictional property of the liquid that tends to prevent it from flowing. Lighter oils that are more refined have lower viscosity than heavier and non-refined crude oils. Viscosity controls the rate that oil spreads and the depth that oil will penetrate into the soil once ashore. The viscosity of spilled oil will generally increase with time due to evaporation of lighter aromatics and emulsification of water and oil. Increases in viscosity make oil much more difficult to pump. Viscous oil is more likely to coat things than it is to penetrate into sediments and debris. As the temperature of an oil decreases, its viscosity dramatically increases. Many skimmers are sensitive to changes of viscosity, which changes the skimmer recovery efficiencies and oil recovery rates.

Oil Spill Processes

Spreading Rate

Spreading rate is probably one of the most important processes because many of the other dispersive processes would not occur largely if the oil did not spread out into a thin film. Evaporation, emulsification, dissolution, dispersion and sedimentation would all be reduced if spreading were slowed down by physical containment or a change in chemical properties. When oil is spilled on the surface of water it floats higher than water and tends to spread out to a point of equilibrium between gravity forces and surface tension

forces. The spreading rate is different for each oil and will decrease with time as the slick thins and gravity forces decrease with a lower differential of oil height above the water. The viscosity also increases with time and slows the rate. When surface tension force equals the gravity force, the slick stops spreading. Some compounds such as NSO tend to reduce the surface tension and promote spreading until they dissolve in the water, at which point the surface tension can increase and contract the spill to some extent.

Advection

Advection is the horizontal (surface) and sometimes vertical (subsurface) transportation of oil caused by currents, turbulent mixing and wind.

Downstream

The major advection process of oil is on the surface in the direction of the surface current. Oil generally moves at the speed of the surface current or slightly slower depending upon the shear forces involved at the oil/water interface. Local knowledge of the waterbody is extremely important to predict the speed and direction of this transport process in order to predict oil movement and plan the appropriate response. Unfortunately, many other factors contribute to variations of the downstream phenomena that will dramatically change the drift of the oil spill.

Eddies

Eddies are currents that run contrary to the main current. Sometimes they form small whirlpools where oil will collect and remain for a long period. Other times eddies form a counter current that moves upstream along the bank for quite a distance. Eddies generally occur on the backside of large rocks, islands or land that jut out into the main flow of the current. On rivers, they often occur on the inboard side of a major turn just around the bend. These areas often are associated with sand or silt beaches. These beach areas tend to make nice staging areas for spill response logistics, however; the oil is generally found on the other side where the current is fast and it has scoured out a deep channel along a steep bank making collection difficult. Eddies also develop inside harbor entrances and breachways during flood tides and just outside these entrances d uring ebb tides. They can hamper or assist in oil spill containment and recovery depending upon the situation at hand. Local knowledge of the waterbody and good circulation observations are required to take full advantage of these circulation currents. Areas where debris collect unfortunately is where oil often collects too.

Reversing Tidal Currents

Tides are a phenomenon of coastal areas of the ocean and large lakes. The moon is the main contributor and the sun is second in importance to the changes of the tidal wave and associated tidal currents. As the tidal wave approaches, water raises and enters bays and rivers, which is called a flood tide. The water level begins to drop and the tide turns, which is called the ebb tide as the water leaves the rivers and harbors. Generally, the time interval between two successive high, or low, waters is 12 hours and 25 minutes. In some locations, this only occurs once a day. The tidal heights and associated currents change based upon the position of the moon and sun, local geography and latitude; however, can be predicted for your local area. These predictions are reliable for the most part but local weather and river runoff can effect predicted tidal currents.

For example, winds can pile up water against a shore or vacate it from the shore effecting the tidal heights and currents. Large fluctuations in barometric pressure can also change currents by changing water heights. Tidal currents in harbors and rivers are also be effected by the volume of fresh water runoff caused by rains, melting snow and dam releases. Excessive river outflows can reduce a flood tide and dramatically increase an ebb tide and currents. Both the magnitude and time of maximum currents can be changed significantly by local weather.

Wind Effects

Wind will cause oil to drift on the surface of the water. Although the speed of the oil will vary slightly depending upon specific conditions, oil will drift at approximately 3.5 percent of the wind velocity. Therefore, a 30-knot wind will cause the oil to drift one knot downwind. Wind driven currents can be added in vector form to the tidal or other currents to obtain the total current magnitude and direction. Wind

is an important factor when developing strategies to contain and recover oil. It can hinder or aid in protection of sensitive areas. Wind can also cause oil to move upstream against the usually predominant current. Some alternate oil control methods incorporate air jets to control oil drift.

Longshore Currents

Longshore currents are currents that run parallel to the shore. These currents are generated by waves breaking while approaching the coast obliquely. Typical values for the longshore currents are about 2 knots. These currents will transport oil quickly down a coast that has significant wave energy. This is an area of high currents where turbulence is often facilitated by breaking waves. Oil will tend to emulsify and pick up sediment that may cause it to sink to the bottom in these areas.

Seiche

Stationary waves in enclosed harbors or lakes are also caused by tides, wind and pressure changes. The period of these oscillations is the characteristic period[57] of the channel, *T*. In a channel of length *l* and depth *h* this period is:

$$T = \frac{2l}{\sqrt{gh}} \tag{B-1}$$

Where, *g* is the acceleration due to gravity. Whenever the characteristic period is much smaller that the tide-generating force, equilibrium tides exist. Whenever the characteristic period is much greater than the tide-generating force, the tides are small and reversed. Whenever the characteristic period approximates that of the tide-generating force, the two oscillations reinforce each other. The closer the periods, the greater the tides and associated tidal currents due to resonance.[57] This seiche period is characteristic for each lake. Seiche related currents are strongest at the equilibrium point approximately midway along the channel length when water is flowing from one end to the other. The characteristic period for lakes and seas is important to know for an understanding of the tidal currents there.

Tidal and seiche currents make oil containment and recovery more difficult for several reasons. Surface currents affect the projected trajectory of an oil spill. Cyclical tidal currents make it more difficult to predict and anticipate where to place containment and diversion boom. Once the boom is moored in place, the current magnitude and direction changes with time due to tidal changes. This will require constant tending of the boom system to ensure it remains positioned properly to do its job. The deflection angle uses should be selected for the maximum current to ensure entrainment of oil under the boom does not occur. When the tide changes and reverses direction the captured oil must be contained to prevent it from being swept out in the opposite direction. Diversion and collection boom may have to be moved or reversed to function properly for the change in tidal current direction. Boom mooring systems must be moved to accommodate these changes. It is most advantageous to move the boom during slack water. The boom however, will have to be tended and probably adjusted as the current intensifies during the next maximum current. Reversing tidal currents very often require special strategies.

Turbulent Mixing and Dispersion

Oil will generally float on the surface of water depending upon relative density of the two liquids. As discussed above, emulsification, evaporation and sedimentation increases the oil density and with less buoyancy it is more likely to sink or be entrained into the water column by turbulent circulation in high currents. The oil will also tend to entrain under booms and skimmers when buoyancy is reduced. Smaller oil droplets are formed in water that is more turbulent and are likely to stay suspended in the water column. Wind and breaking waves facilitate mixing and natural dispersion. The hydraulic energy increases with the square of the current speed and square of the wave height. Turbulence is also caused by flow past obstacles such as rocks, bridge supports and pilings.

Bottom roughness and local depth of water are major factors in the mixing oil in water for rivers and coastal areas with high currents. Mixing caused by flow past obstacles that pierce the surface is going to

generate more mixing energy than bottom roughness and surface waves because the surface is broken. An equation[3] that is applicable to dissipation energy, D in rivers is represented as:

$$D = \kappa r_s \rho u^2 H_e / d \tag{B-2}$$

Where,
D = dissipation energy (J/m^2)
κ = Von Karman's constant = (0.4)
r_s = bottom roughness (m)
Δ = water density (kg/m^3)
u = current speed (m/sec)
H_e = hydraulic energy height where, $H_e = u^2/2g$
g = gravitational acceleration (m/sec^2)
d = local depth (m)

Therefore, low water depth and high current facilitate oil entrainment and dispersion due to turbulent mixing.

Salt Wedge

Salt water adjacent to fresh water from rivers and estuaries will tend to intrude in a submerged wedge of saltwater up into the fresh water source. The denser and usually colder salt water will form a stratified flow that reduces vertical mixing of the water column. This saltwater intrusion will extend farther up a river or estuary when freshwater runoff is reduced, generally in the summer season. This can affect surface flow patterns and reduce sedimentation and dispersion of oil during a flood tide. During ebb flow, vertical shears become so large that the stratification becomes unstable, and the salt wedge structure breaks down. During ebb tides, salt wedge deterioration can precipitate surface mixing and oil submergence.

Weathering

In addition to spreading, a number of natural physical, chemical and biological processes begin to occur to remove or change the oil characteristics. These weathering processes include evaporation, dissolution, dispersion, emulsification, sedimentation, biodegradation and photo-oxidation.

Evaporation

Many lighter oils will tend to be completely lost by evaporation. Even heavier oils will loose a significant portion of their volume due to evaporation depending upon the conditions. The rate of evaporation depends upon the boiling point distribution of the hydrocarbon compounds. Evaporation rates will increase with temperature and wind speed. If the oil is in a confined containment or geographic area, the rate of evaporation will be reduced due to restricted spreading.

Dispersion

The agitation of oil slicks due to waves, wind, high currents and turbulence supplies energy to form small droplets and then mix them in the water column. Mechanically dispersed oil will tend to agglomerate and form larger droplets until they float back to the surface. NSO compounds with hydrophilic groups in petroleum can act as natural surface-active agents or surfactants. These natural compounds and man made dispersants (soaps) can also accelerate dispersion. The increased surface area resulting from dispersion increases the rate of dissolution, sedimentation and biodegradation.

Sedimentation and Sinking

Small-suspended bottom sediments are also dispersed into the water column due to waves, wind, high currents and turbulence. These sediments will adhere to the oil droplets and the surface slick making it heavier. This process will increase the specific gravity thus reducing buoyancy of the oil, increasing suspension and sometimes sinking it to the bottom. This process makes oil recovery much more difficult.

Emulsification

An emulsion is a mixture of two mutually insoluble liquids in which one is dispersed in droplet throughout the other. Emulsions are readily formed in high-speed currents and associated turbulence where agitation is supplied by the energy in the system (tidal and river currents). Waves and wind will also contribute to formation of emulsions. Water-in-oil emulsions referred to as chocolate mousse will increase in volume by 50 to 80 percent due to the captured and suspended water droplets. This makes retrieval more difficult due to increased viscosity, lower buoyancy and higher volume of the oil slick.

Oxidation

Photo-oxidation occurs when ultra-violet light causes chemical reactions of oil. Hydrocarbons may oxidize to oxygen containing compounds that are more soluble or more toxic than oil. Fast water and associated turbulent mixing will reduce photo-oxidation by removing some oil from the surface.

Biodegradation

The assimilation of oil by microorganisms is a slow natural process that is more important as a long-term remediation process. This may be accelerated by turbulent mixing by increasing the surface area of oil droplets to the bacteria that ingest them.

Appendix C Environmental Effects of Oil Spills

Table C-1. Properties of Common Oil Types and Possible Adverse Effects during Oil Spills[1]

Oil Type	Physical and Chemical Properties	Adverse Effect on Environment
Light to Volatile Oils	• Spread rapidly • Tend to form unstable emulsions • High evaporation and solubility • May penetrate substrate • Removed from surfaces by agitation and low-pressure flushing. • Removed from water using weirs, inclined plane skimmers, air conveyor and vacuum trucks and rope mops.	• Toxicity is related to the type and concentration of aromatic fractions and the biota resistance • Toxic to biota when fresh • Mangroves, marsh and wetland plants may be chronically effected due to penetration and persistence of aromatics compounds in sediments • Marine and wetland plants may be adversely affected by smothering.
Moderate to Heavy Oils	• Moderate to high viscosity • Tend to form stable emulsions under high energy environments • Weathered residue may sink and be adsorbed by sediment • Immiscibility assists in separation from water • Removed from water using weirs, oleophilic, inclined planes skimmers, air conveyors and vacuum trucks. • Weathers into tar balls	• Adverse effects in marine organisms result from chemical toxicity and smothering • Toxicity varies depending on light fractions • Toxic effects reduced in tropical climates due to rapid evaporation and weathering • Low toxicity residue tends to smother plants and animals • Light fractions contaminate interstitial waters
Asphalt, No. 6 fuel oil, Bunker C	• Form tarry lumps • Resist spreading and may sink • May soften and flow when exposed to sunlight • Difficult to recover from the water and pump. Positive displacement pumps are required. • Easy to remove from beach surfaces with conventional equipment. Brush and lifting belt skimmers are generally effective.	• Immediate and delayed adverse effects due to small aromatic fractions and smothering • Most toxic effects due to incorporation into sediment • Absorption of radiated heat places thermal stress on the plants and animals • Lower toxicity in marine plants than mobile animals.

Table C-2. Shoreline Classification in Order of Decreasing Environmental Sensitivity Damage[1]*

Ecological Sensitive Index	Shoreline Type	Effect on Environment
10 (high)	Salt Marches, Mangroves and Wetlands.	• Most productive of aquatic environments • Very low flushing energy • High sedimentation rate incorporates oil into the sediment • Cleanup may do more harm than letting oil naturally degrade • Dispersants or cleaners may help more than mechanical cleaning • Oil may persist for years • Area should receive top priority for protection
9	Sheltered Tidal Flats, Floodplains, Small Rivers & Streams and Vegetated Shoreline	• High biomass to be affected • Low currents and wave action • Oil may persist for years • Removal of heavy oil concentrations is necessary; otherwise cleanup is not necessary • Area should receive priority protection from oil impact
8	Sheltered Rocky Coasts and Man-made Structures	• Moderate to high biomass to be affected • Areas of reduced currents and wave action • Oil may damage the intertidal zone • Oil may persist for many years • Removal of heavy oil concentrations is necessary • High priority for protection and cleanup
7	Exposed Tidal Flats–Vegetated and Fresh Water Mud Habitats	• Moderate biomass to be affected • Sediments less mobile • Most oil will not penetrate sediments • Oil may persist for about one year
6	Gravel Beaches	• Oil may penetrate rapidly, making cleanup difficult • Cleanup should concentrate on high tide wash area. • Oil may persist several years in sheltered locations
5	Exposed Tidal Flats	• Low biomass to be affected • Mobile sediments • Most oil will not penetrate sediments • Natural processes will remove most oil in about one year
4	Course–Grained Sand Beaches	• Low biomass to be affected • Oil may penetrate or be buried rapidly making cleanup difficult • Uncleaned, most oil will be naturally removed within several months
3	Exposed Fine to Medium Sand Beaches and River Bedrock	• Low biomass to be affected • Oil does not penetrate into the beach • Mechanical removal is effective • Natural processes will remove most oil within a few months
2	Wave–Cut Coastal Platforms	• Wave swept, usually erosional • Natural processes will usually remove oil within weeks
1 (low)	Exposed Rocky Headland	• Wave reflections keep most of the oil offshore • Cleanup may not be necessary

* Modified to include inland shoreline types in addition to coastline shoreline types.

APPENDIX D Oil Spills 1992-1997

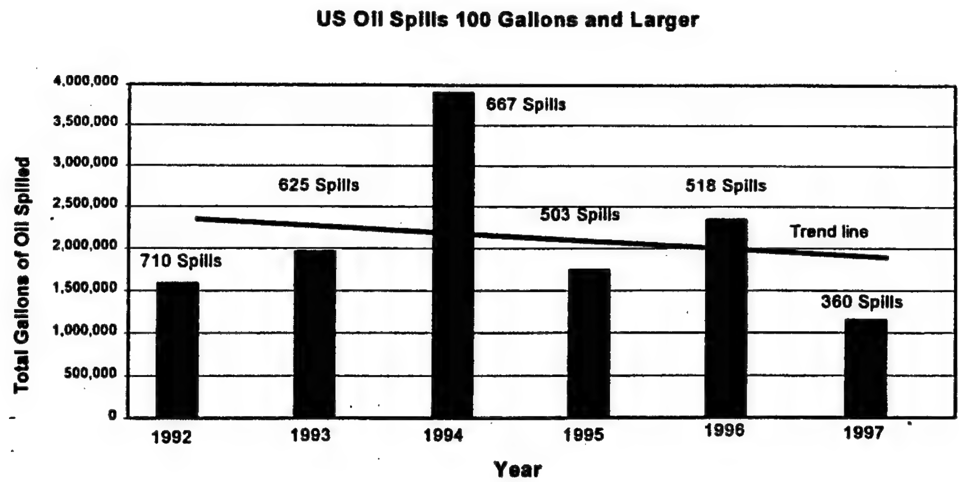


Figure D-1. Annual US Oil Spills, 1992 to 1997

Table D-1. Total Oil Spilled by Waterbody from 1992 to 1997 (Spills 100 Gallons and Larger)

OIL SPILLED (GALLONS)	NUMBER OF OIL SPILLS	WATERBODY	STATE(S)	CURRENTS > 1 knot	OIL SPILLED IN FAST WATERS (GALLONS)
3,446,722	923	NAVIGABLE WATERS NEC	MOST COASTAL STATES		
2,020,904	85	HOUSTON SHIP CHANNEL, TX	TX	Yes	2,020,904
833,326	85	NORTH ATLANTIC OCEAN COASTAL	EAST COAST & PR		
793,718	118	LOWER MISSISSIPPI RIVER	MO, AR, KY TN, MS & LA	Yes	793,718
615,486	259	GULF OF MEXICO	TX, LA & FL		
369,567	16	TAMPA BAY, FL	FL	Yes	369,567
369,127	13	POTOMAC RIVER, VA	VA	Yes	369,127
209,853	11	ATCHAFALAYA RIVER. LA	LA	Yes	209,853
209,597	195	NORTH PACIFIC OCEAN COASTAL	WEST COAST, AK & HI		
150,280	23	NORTH PACIFIC OCEAN			
144,172	70	INTERCOASTAL WTRWY-GULF	GULF COAST		
135,914	44	UPPER MISSISSIPPI RIVER	MO, MN, IL, IN & IO	Yes	135,914
122,030	3	TIMBALIER BAY, LA	LA		
103,430	8	NORTH PACIFIC OCEAN CONTIG ZN	WEST COAST & GU		
98,559	29	SABINE/NECHES RIVER, TX	TX		98,559
85,740	69	SAN DIEGO HARBOR, CA	CA		
82,794	35	CORPUS CHRISTI SHP CHNL & HBR	TX		82,794
82,429	45	NON NAVIGABLE WATERS NEC			
82,213	39	CHESAPEAKE BAY (VA & MD)	VA & MD		
78,620	38	PATAPSCO RIVER, MD	MD		
73,836	13	NON WATERBODY			
72,814	65	PUGET SOUND, WA	WA	Yes	72,814

Table D-1 Continued

OIL SPILLED (GALLONS)	NUMBER OF OIL SPILLS	WATERBODY	STATE(S)	CURRENTS > 1 knot	OIL SPILLED IN FAST WATERS (GALLONS)
71,366	74	ELIZABETH RIVER, VA	VA		
68,068	35	NORTH ATLANTIC OCEAN			
51,033	60	DELAWARE RIVER	DE, NJ & PA	Yes	51,033
49,385	32	ST. JOHNS RIVER	FL	Yes	49,385
45,226	5	DELAWARE BAY	DE	Yes	45,226
44,800	89	SOUTH PACIFIC OCEAN COASTAL	AS & GU		
44,567	21	LAKE ERIE	NY, OH & PA		
41,600	10	PEARL HARBOR	HI		
40,861	16	MOBILE RIVER	AL		
40,382	45	OHIO RIVER	OH, IL, IN, KY, PA & WV	Yes	40,382
38,635	17	LONG ISLAND SOUND	CT & NY	Yes	38,635
38,530	19	PORT CANAVERAL	FL		
35,813	20	EAST RIVER	NY	Yes	35,813
29,412	13	DETROIT RIVER	MI	Yes	29,412
27,115	17	ARKANSAS RIVER	AR	Yes	27,115
25,180	21	BAYOU LAFOUCHE	LA		
23,960	9	SCHUYLKILL RIVER	PA		
22,415	25	CARIBBEAN SEA	PR & VI		
22,268	43	INTERCOASTAL WTRWY-ATLANTIC	EAST COAST		
16,808	33	PORT OF LA/LB	CA		
15,870	20	SAN FRANCISCO BAY	CA	Yes	15,870
15,535	16	PRINCE WILLIAM SOUND	AK	Yes	15,535
12,988	14	KILL VAN KULL	NJ	Yes	12,988
12,594	15	SAN JUAN HBR(BAHIA DE SN JN)	PR		
12,450	12	BERING SEA	AK		
10,650	13	LAKE MICHIGAN	IL, IN & WI		
10,305	14	HUDSON RIVER (N OF 41 00 N)	NY	Yes	10,305
9,831	17	COLUMBIA RIVER	OR	Yes	9,831
9,720	9	CUYAHOGA RIVER	OH		
8,982	13	GALVESTON BAY	TX	Yes	8,982
8,850	15	NEWARK BAY-HKNSK & PASSAIC R	NJ		
8,700	5	ALLEGHENY RIVER	PA	Yes	8,700
8,652	3	MAUMEE RIVER	OH		
8,146	3	FREDERICK SOUND	AK		
8,104	12	WILLAMETTE RIVER	OR	Yes	8,104
6,900	7	NORTH ATLANTIC OCN CONTIG ZN			
6,830	17	LAKE WHSNGTN SC/LAKE UNION	WA		
6,560	9	CHARLESTON HARBOR	SC	Yes	6,560
6,450	14	HUDSON RIVER(BATTERY-41 00N)	NY	Yes	6,450
6,176	10	JAMES RV(INC NORFOLK/NWPT NS)	VA	Yes	6,176
6,000	2	BUZZARDS BAY	MA		
5,799	6	BRISTOL BAY	AK		
5,600	2	PORT ALLEN ROUTE	LA		
5,500	12	NEW YORK HARBOR UPPER BAY	NY	Yes	5,500
5,375	15	HONOLULU HARBOR	HI		
4,965	10	LIMETREE BAY (ST. CROIX)	VI		
4,800	6	MONONGAHELA RIVER	PA		

Table D-1 Continued

OIL SPILLED (GALLONS)	NUMBER OF OIL SPILLS	WATERBODY	STATE(S)	CURRENTS > 1 knot	OIL SPILLED IN FAST WATERS (GALLONS)
4,000	1	NORTON SOUND	AK		
3,650	4	RARATAN RIVER	NJ		
3,606	6	NEW YORK HARBOR LOWER BAY	NY	Yes	3,606
3,075	10	BOSTON HARBOR	MA		
2,800	2	BIG SANDY RIVER	KY	Yes	2,800
2,769	9	MISSISSIPPI SOUND	MS		
2,670	8	BALTIMORE HARBOR	MD	Yes	2,670
2,600	1	DIXON ENTRANCE COASTAL	AK		
2,600	6	LAKE SUPERIOR	MI & MN		
2,500	1	TOMBIGBEE RIVER	AL	Yes	2,500
2,496	5	MOBILE BAY	AL	Yes	2,496
2,450	11	SAVANNAH RIVER	GA	Yes	2,450
2,320	7	CAPE FEAR RIVER	NC	Yes	2,320
2,230	3	CHICAGO SHIP CANAL	IL		
2,226	2	LAKE PONTCHARTRAIN	LA		
2,100	12	MIAMI RIVER	FL	Yes	2,100
1,970	5	LAKE HURON	MI		
1,930	5	ILLINOIS RIVER	IL	Yes	1,930
1,770	9	TENNESSEE RIVER	TN, KY & AL	Yes	1,770
1,620	4	CUMBERLAND RIVER	KY	Yes	1,620
1,445	2	CAPE COD BAY	MA		
1,400	3	PENOBSCOT BAY	ME		
1,234	5	STRAIT OF JUAN DE FUCA	WA	Yes	1,234
1,050	5	KANAWHA RIVER	WV	Yes	1,050
900	3	PORT EVERGLADES	FL	Yes	900
900	2	ST. CLAIR RIVER	MI	Yes	900
800	1	YUKON RIVER	AK		
750	3	PISCATAQUA RIVER	NH	Yes	750
660	4	PORT OF MIAMI	FL	Yes	660
650	6	NARRAGANSETT BAY	RI		
650	4	PORTLAND HARBOR/RIVER	ME		
650	2	SAN PEDRO BAY	CA		
600	1	GRAY'S HARBOR	WA	Yes	600
500	2	MUSCONGUS BAY	ME		
500	2	NANTUCKET SOUND	MA		
450	2	SITKA SOUND	AK		
420	1	SOUTHWEST PASS-AHP TO GOM	LA		
400	3	YORK RIVER	VA		
375	2	ROUGE RIVER	MI		
368	2	HOUMA CHANNEL	LA		
360	2	ST. MARYS RIVER (MICH)	MI		
300	3	LAKE ST. CLAIR	MI		
300	2	SACRAMENTO RIVER	CA		
300	1	ST. LAWRENCE RIVER	NY	Yes	300
275	1	CASCO BAY	ME		
250	2	CONNECTICUT RIVER	CT	Yes	250
150	1	KENTUCKY RIVER	KY	Yes	150

Table D-1 Continued

OIL SPILLED (GALLONS)	NUMBER OF OIL SPILLS	WATERBODY	STATE(S)	CURRENTS > 1 knot	OIL SPILLED IN FAST WATERS (GALLONS)
140	1	LAKE ONTARIO	NY		
7,812,324 Sum (excluding "navigable waters nec" data)					Sum 4,519,749

Percent of Oil Spilled on Fast Waterways (excluding "navigable waters nec" data) **58%**

Annually 753,392 (GAL)

Table D-2. Total Oil Spilled by State & Offshore Location from 1992 to 1997
(Spills 100 Gallons and Larger)

OIL SPILLED (GALLONS)	NUMBER OF OIL SPILLS	State/Territory	Location
2,695,611	265	Texas	
1,996,478	458	Louisiana	
971,041	33	South Carolina	
823,089	54	Puerto Rico	
784,525	37	Georgia	
615,486	259	Offshore TX, LA & FL	Gulf of Mexico
533,913	180	Florida	
518,448	132	Virginia	
249,553	161	California	
198,630	31		North Pacific Ocean
196,882	203	Alaska	
146,877	138	New York	
120,845	92	Maryland	
119,082	22	Missouri	
91,964	69	Pennsylvania	
88,737	51	Alabama	
86,724	99	Washington	
83,050	12	Connecticut	
78,168	47		North Atlantic Ocean
77,483	56	Hawaii	
70,660	79	New Jersey	
67,661	42	Ohio	
52,783	59	Massachusetts	
47,676	9	Delaware	
44,425	22	Arkansas	
42,635	34	Michigan	
42,110	84	American Somoa	
37,035	39	Mississippi	
36,461	20	Tennessee	
28,175	49	Oregon	
25,814	20	Kentucky	
18,877	16	West Virginia	

Table D-2 Continued

OIL SPILLED (GALLONS)	NUMBER OF OIL SPILLS	State/Territory	Location
15,544	43	North Carolina	
15,427	30	Illinois	
13,749	40	Guam	
13,340	3	Wisconsin	
12,400	10	Minnesota	
10,720	31	Maine	
9,320	14	Indiana	
7,425	18	Virgin Islands	
4,650	3	Idaho	
3,888	14	Rhode Island	
1,600	1	District of Columbia	
750	3	New Hampshire	

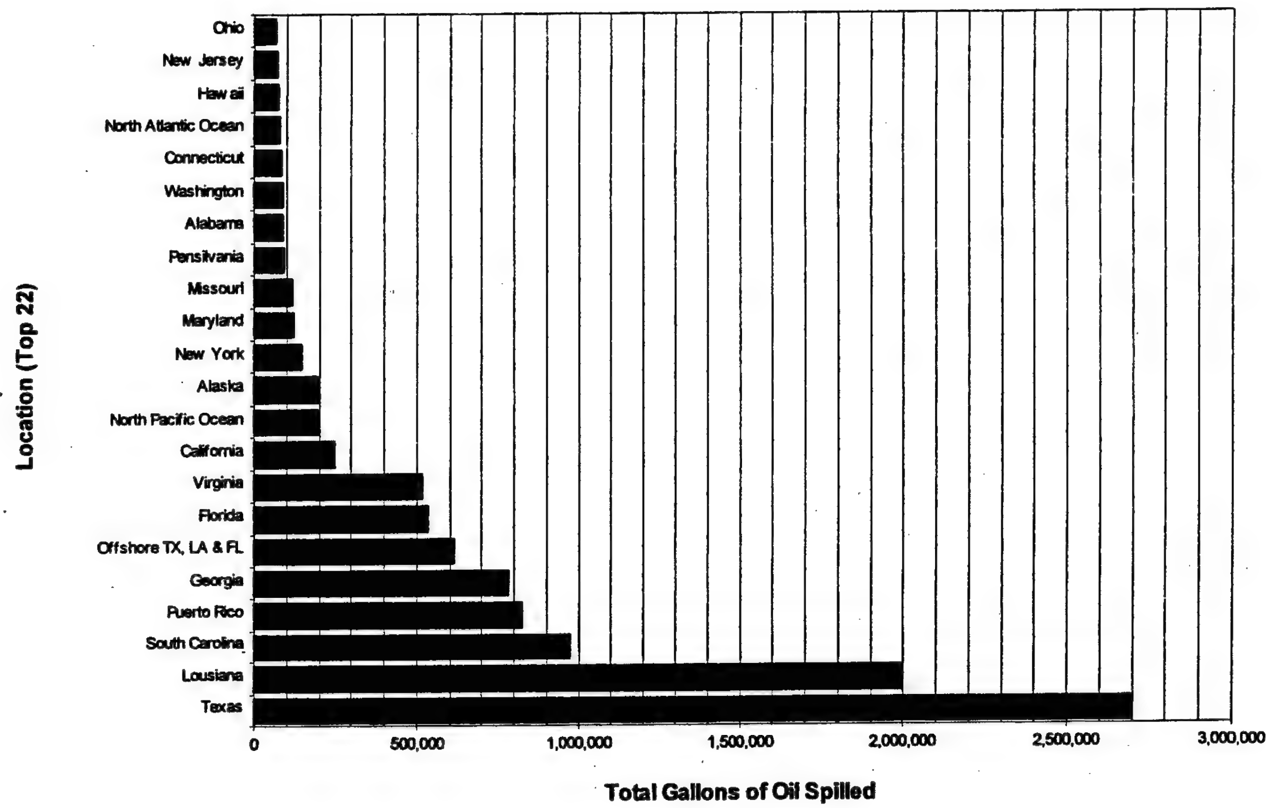


Figure D-2. Oil Spilled in Waterways by State and Offshore Locations from 1992 to 1997

APPENDIX E Waterways with Fast Currents

Table E-1. Representative Waterways and Associated Maximum Currents

Tidal Currents of Bays, Harbors and Rivers

Based upon Reed's Nautical Almanac (East & West Coast North America Editions 1998)[6]

Place	State	Flood (knots)	Ebb (knots)	Position Latitude (degrees & minutes)	Position Longitude (degrees & minutes)	Notes
West Coast						
San Clemente Island	CA	0.4	0.2	32 29.0	118 32.0	
San Diego Bay Entrance	CA	1.2	1.5	32 40.9	117 13.8	Max currents diminish in the harbor to 0.2 to 0.7 knot.
San Francisco Bay Entrance	CA	2.9	3.4	37 48.6	122 30.1	Max currents diminish in the harbor to 0.5 to 2.6 knots.
Humbolt Bay Entrance	CA	1.6	2	40 45.0	124 14.0	
Sacramento River Entrance	CA	1.2	1.3	38 03.0	121 52.0	
Coos Bay Entrance	OR	1.8	2.2	43 21.0	124 20.0	
Yaquina Bay Entrance	OR	2.4	2.3	44 37.0	124 04.0	
Columbia River	OR/WA	3	4.4	46 15.2	123 59.4	Maximum currents diminish up river to some extent.
Grays Harbor	WA	2.5	1.7	46 56.0	124 10.0	
Strait of Juan de Fuca	WA	0.6	1.5	48 27.0	124 35.0	
Admiralty Inlet (Point Wilson)	WA	2.4	2.8	48 10.0	122 46.0	
Puget Sound (The Narrows)	WA	3.2	2.8	47 18.0	122 33.0	Max currents diminish in other areas from 0.1 to 2.8 kts
San Juan Channel (S Entrance)	WA	2.6	2.6	48 28.0	122 57.0	Maximum currents vary from 0.5 to 2.4 kts.
Prince William Sound	AK	0.8	2.4	60 02.2	148 08.0	Maximum currents are lower throughout most of the Sound.
Cordova Bay (Cape Muzon)	AK	1.2	1.2	54 40	132 32.0	Maximum currents vary in the bay from 0.2 to 2.0 knots
Frederick Sound (Cosmos Point)	AK	0.4	0.5	56 40.0	132 36.0	
Cook Inlet (Cape Elizabeth)	AK	2.2	1.8	59 07.2	151 53.7	Maximum currents vary in the Inlet from 0.7 to 4.4 knots.

East Coast

Place	State	Flood (knots)	Ebb (knots)	Latitude (degrees & minutes)	Longitude (degrees & minutes)	Notes:
Penobscott River (Verona Island)	ME	1.5	3.6	44 31.7	68 48.3	
Eastport-Penobscot Bay	ME	3.0	3.0	44 54.0	66 59.0	
Casco Bay (Broad Sound)	ME	0.9	1.3	43 42.7	70 03.8	
Portland Harbor (Entrance)	ME	1.0	1.1	43 37.9	70 12.7	Lower maximum currents in the harbor from 0.4 to 0.9 kts.
Piscataqua River (Dover Pt Bridge)	ME/NH	2.8	2.7	43 07.1	70 50.2	
Boston Harbor (Deer Is. Light)	MA	1.5	1.2	42 20.0	70 57.4	Maximum currents vary in the harbor from 0.1 to 1.2 knots.
Cape Cod Bay (Race Point)	MA	1.5	1.5	42 11.0	70 16.0	Maximum currents in the bay vary from 0.3 to 1.4 knots.
Buzzards Bay (Ribbon Reef)	MA	0.8	1.2	41 25.3	70 58.2	
Cape Cod Canal (RR Bridge)	MA	4.0	4.5	41 44.5	70 36.8	
Woods Hole (Devil's Foot Is.)	MA	3.5	3.6	41 31.2	70 41.1	
Pollock Rip Channel (east end)	MA	2.0	1.8	41 33.9	69 55.4	
Narragansett Bay (Patience Is)	RI	0.7	0.9	41 39.5	71 21.2	Maximum currents in the bay vary from 0.2 to 1.3 knots.
Point Judith (Pond Entrance)	RI	1.8	1.5	41 23.0	71 31.0	
Connecticut River (Saybrook Pt)	CT	1.5	1.5	41 17.0	72 20.9	
Long Island Sound (The Race)	NY/CT	2.9	3.5	41 14.2	72 03.6	
Block Island Sound (Montauk Pt)	NY	2.8	2.8	41 04.5	71 49.8	
East River (Hell Gate)	NY	3.4	4.6	40 46.7	73 56.3	
New York Harbor, Upper Bay	NY	1.4	1.5	40 37.9	74 03.4	
New York Harbor, Lower Bay	NY	1.6	1.9	40 29.1	74 00.1	
Hudson River entrance	NY	1.4	1.4	40 42.5	74 01.2	
Raritan River (Washington Canal)	NJ	1.5	1.5	40 28.3	74 22.1	
Kill Van Kull	NJ/NY	1.3	1.9	40 39.0	74 05.1	
Cape May (Harbor Entrance)	NY	1.8	2.2	38 57.0	74 52.0	
Delaware Bay Entrance	NJ/DE	1.4	1.3	38 46.8	75 02.6	
Delaware River (Reedy Is)	NJ/DE	2.4	2.6	39 30.7	75 33.4	
Delaware River (Essington Harbor)	PA	1.4	1.2	39 51.5	75 18.3	

Place	State	Flood	Ebb	Latitude	Longitude
Chesapeake Bay (Cape Henry Lt.)_	VA	1.3	1.3	37 00.1	75 59.3
Chesapeake Bay (Smith Island)	MD	0.5	0.4	38 00.4	76 07.3
Baltimore Approach (off Sandy Pt.)	MD	1.2	1.1	39 00.8	76 22.1
Patapsco River	MD	weak and variable		39 10.7	76 26.6
Chesapeake Bay (Cape Henry Lt.)	VA	1.2	1.1	36 57.5	76 00.6
Potomac River (White Pt.)	VA	1.2	1.2	38 08.1	76 43.3
York River (Entrance Channel)	VA	1.0	1.0	37 07.4	76 09.2
James River (Newport News)	VA	0.9	1.3	36 58.8	76 26.5
Cape Fear River (Bald Head)	NC	2.2	2.9	33 52.4	78 00.4
Beaufort Inlet (Schackleford Banks)	NC	1.4	1.5	34 39.8	76 39.3
Charleston Harbor (Entrance)	SC	1.8	1.8	32 44.0	79 50.0
Port Royal Sound (Plantation Twr.)	SC	1.5	1.9	32 13.4	80 39.4
Savannah River (Fort Pulaski)	GA	2.2	2.8	32 02.7	80 55.9
Willimington River (Entrance)	GA	1.2	1.7	31 56.3	80 58.6
Saint Johns River (Mayport)	FL	2.2	3.1	30 23.6	81 26.0
Port Everglades (Turning Basin)	FL	0.9	1.8	26 05.8	80 07.1
Miami Harbor (Entrance)	FL	1.8	1.6	25 45.9	80 08.2
Tampa Bay (Entrance)	FL	1.3	1.3	27 36.3	82 45.6
Mobile Bay (Entrance)	AL	1.4	1.5	30 13.6	88 03.2
Mobile River (Entrance)	AL	0.3	0.7	30 40.2	88 02.0
Mississippi Sound (Pascagoula Ri.)	LA	1.2	1.2	30 22.3	88 33.8
New Orleans (Seabrook Bridge)	LA	1.2	0.9	30 01.9	90 02.1
Lower Mississippi River	LA/MS	1 to 9 knots variable due to location & rain			
Sebin Pass	TX	1.6	1.7	29 43.4	93 51.7
Galveston Bay (Entrance)	TX	1.7	2.3	29 20.8	94 42.3
Houston Ship Channel	TX	1.3	1.8	29 30.2	94 52.5

Typical Surface Current Velocity of Inland Rivers

Based upon US Army Corps of Engineers River Flow Data.

Place	State	Surface Current (knots)
Inland Rivers		
Upper Columbia River	OR/WA	3.0
Lower Columbia River	OR/WA	2.4
Willamette River	OR	3.0
Upper Mississippi River	IL/IA	1.8
Uppper Missouri River	IA/NE	3.1
Lower Missouri River	MO	3.0
Illinois River	IL	1.5
Upper Ohio River	WV/OH	2.9
Middle Ohio River	IN/KY	3.2
Lower Ohio River	KY/IL	3.5
Tennessee River	TN	0.6
Lower Mississippi River	TN/AR	4.2
Lower Mississippi River	MS/LA	4.7
Mississippi River (mouth)	LA	2.3
Upper Tombigbee River	AL/MS	1.5
Lower Tombigbee River	MS	2.0
Black Warrior River	MS	1.9
St. Claire River/Detroit River	MI	2.4
Corpus Christi Ship Channel	TX	2.0
St. Mary's River	FL/GA	2.0
Housatonic River	CT	1.2

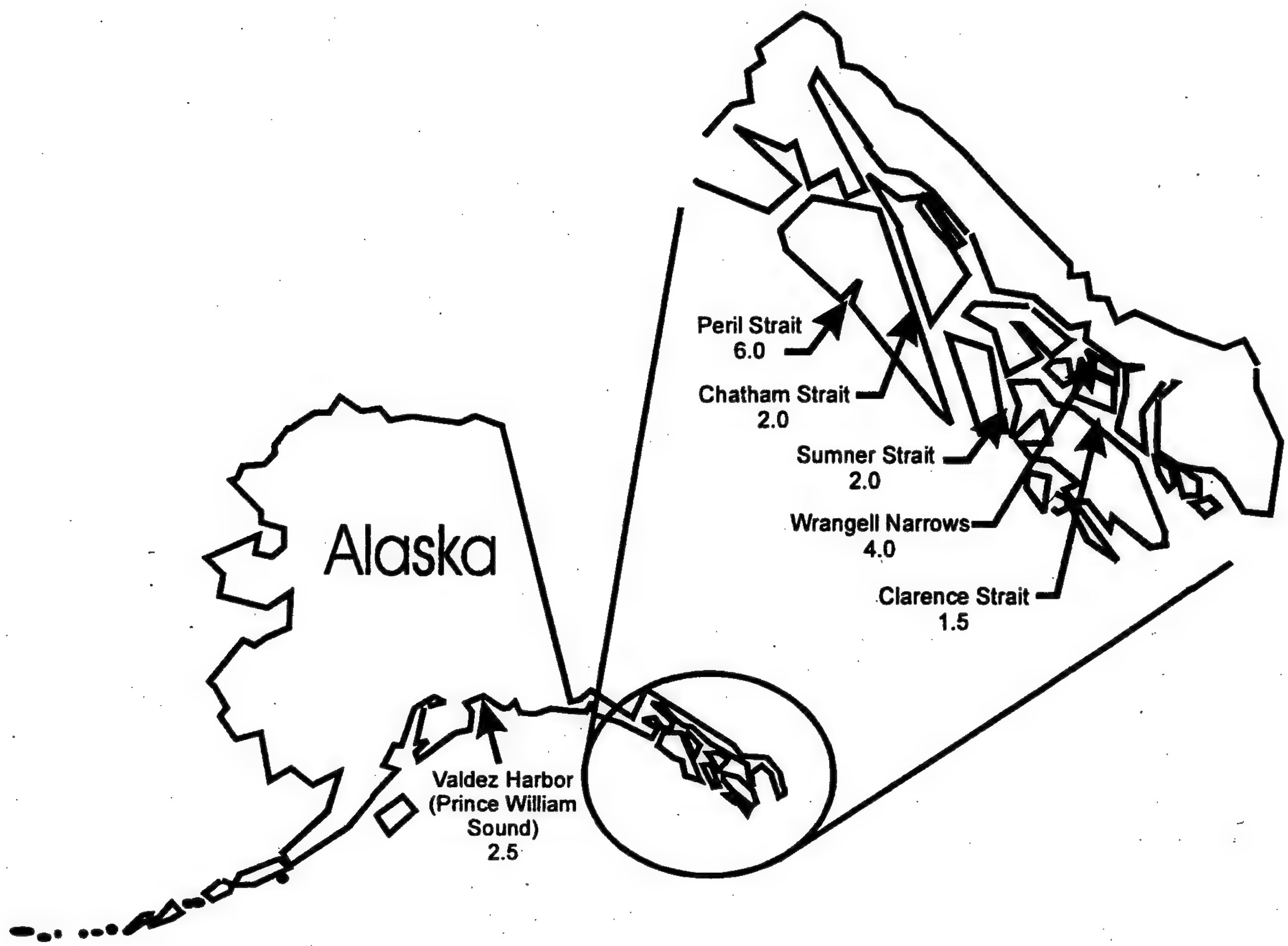


Figure E-1. Fast Current Waterbodies of Alaska

APPENDIX F Oil Transportation Statistics 1992-1996

Table F-1. Oil Transported Annually on US Waterways and Ports

Oil Transported On All US Waterways (no overlap)
Average Annual 1992-1996

Waterway	Oil (tons)
MISSISSIPPI RIVER SYSTEM	99,748,242
DELAWARE RIVER, (TRENTON, NJ TO THE SEA)	91,438,848
PORT OF NEW YORK (SUMMARY)	85,558,941
VALDEZ HARBOR, AK (Prince William Sound)	84,469,900
HOUSTON SHIP CHANNEL, TX (HOUSTON, TX)	76,869,681
CORPUS CHRISTI SHIP CHANNEL, TX	51,086,019
GULF INTRACOASTAL WATERWAY (FL TO MEXICO)	48,093,748
SAN FRANCISCO BAY ENTRANCE, CA	41,903,729
LONG BEACH HARBOR, CA	26,458,059
PASCAGOULA HARBOR, MS	20,962,514
OTHER PUGET SOUND AREA PORTS, WA	19,686,693
LOS ANGELES HARBOR, CA	16,675,585
BEAUMONT, TX (NECHES RIVER)	15,684,593
PORT OF BOSTON, MA	14,213,653
PORT EVERGLADES HARBOR, FL	13,315,144
ANACORTES HARBOR, WA	12,778,135
TAMPA HARBOR, FL	12,589,154
PORTLAND HARBOR, ME	12,233,296
FREEPORT HARBOR, TX (FREEPORT, TX)	11,481,243
PORT OF PLAQUEMINES, LA	9,460,701
JACKSONVILLE HARBOR, FL	8,541,772
CAPE COD CANAL, MA	7,842,592
MOBILE HARBOR, AL	7,792,217
BARBERS POINT HARBOR, OAHU, HI	7,517,627
NEW HAVEN HARBOR, CT	7,137,763
COLUMBIA RIVER SYSTEM	6,002,012
SAN JUAN HARBOR, PR	5,961,295
PORT OF PORTLAND, OR	5,873,618
YORK RIVER, VA	5,696,303
PROVIDENCE RIVER AND HARBOR, RI	5,244,735
HAMPTON ROADS, VA	4,485,740
BALTIMORE HARBOR AND CHANNELS, MD	3,862,917
GALVESTON CHANNEL, TX (GALVESTON, TX)	3,832,331
TACOMA HARBOR, WA	3,659,329
NORFOLK HARBOR, VA	3,416,750
LONG ISLAND SOUND ENTRANCE TO NEW YORK	3,358,288
SEATTLE HARBOR, WA	3,278,730
CHARLESTON HARBOR, SC	2,967,542
NIKISHKA, AK	2,721,682
SUISUN BAY CHANNEL, CA	2,400,750
WILMINGTON HARBOR, NC	2,253,365
CHOCOLATE BAYOU, TX	2,112,600
VICKSBURG, MS	2,071,072
HONOLULU HARBOR, OAHU, HI	2,023,720
PORT JEFFERSON HARBOR, NY	2,001,074
CANAVERAL HARBOR, FL	1,985,604
BRIDGEPORT HARBOR, CT	1,912,691
PORTSMOUTH HARBOR, NH	1,859,534
LAKE MICHIGAN	1,620,049
PENOBSCOT RIVER, ME	1,575,509
POTOMAC RIVER BELOW WASHINGTON, DC	1,516,375
MIAMI HARBOR, FL	1,495,743
WILMINGTON HARBOR, DE	1,446,415
BLACK WARRIOR AND TOMBIGBEE RIVERS, AL	1,327,643
BAYOU LAFOURCHE AND LAFOURCHE-JUMP WATERWAY, LA	1,197,488
PORT OF NEWPORT NEWS, VA	1,136,721
BRAZOS ISLAND HARBOR (BROWNSVILLE & PORT ISABEL, TX)	1,135,859
CHARLOTTE HARBOR, FL	936,739

Oil Transported On Fast US Waterways*
Average Annual 1992-1996

Waterway	Oil (tons)
MISSISSIPPI RIVER SYSTEM	99,748,242
DELAWARE RIVER, (TRENTON, NJ TO THE SEA)	91,438,848
PORT OF NEW YORK (SUMMARY)	85,558,941
VALDEZ HARBOR, AK (Prince William Sound)	84,469,900
HOUSTON SHIP CHANNEL, TX (HOUSTON, TX)	76,869,681
CORPUS CHRISTI SHIP CHANNEL, TX	51,086,019
SAN FRANCISCO BAY ENTRANCE, CA	41,903,729
PASCAGOULA HARBOR, MS	20,962,514
OTHER PUGET SOUND AREA PORTS, WA	19,686,693
JACKSONVILLE HARBOR, FL	8,541,772
CAPE COD CANAL, MA	7,842,592
MOBILE HARBOR, AL	7,792,217
NEW HAVEN HARBOR, CT	7,137,763
COLUMBIA RIVER SYSTEM	6,002,012
PORT OF PORTLAND, OR	5,873,618
HAMPTON ROADS, VA	4,485,740
BALTIMORE HARBOR AND CHANNELS, MD	3,862,917
GALVESTON CHANNEL, TX (GALVESTON, TX)	3,832,331
LONG ISLAND SOUND ENTRANCE TO NEW YORK	3,358,288
CHARLESTON HARBOR, SC	2,967,542
WILMINGTON HARBOR, NC	2,253,365
PORT JEFFERSON HARBOR, NY	2,001,074
PORTSMOUTH HARBOR, NH	1,859,534
PENOBSCOT RIVER, ME	1,575,509
POTOMAC RIVER BELOW WASHINGTON, DC	1,516,375
MIAMI HARBOR, FL	1,495,743
BLACK WARRIOR AND TOMBIGBEE RIVERS, AL	1,327,643
ST. JOHNS RIVER, FL JACKSONVILLE TO LAKE HARNEY	775,445
PENSACOLA HARBOR, FL	636,999
CONNECTICUT RIVER BELOW HARTFORD, CT	603,842
JAMES RIVER, VA (CONSOLIDATED REPORT)	512,492
DETROIT RIVER, MI	469,261
ST. CLAIR RIVER, MI	457,944
HUMBOLDT HARBOR AND BAY, CA	291,141
ST. LAWRENCE RIVER, US/CANADA	218,812
CAPE FEAR RIVER ABOVE WILMINGTON, NC	205,738
COLORADO RIVER & FLOOD DISCHARGE CHANNELS, TX	169,612
BELLINGHAM BAY AND HARBOR, WA	134,608
COOS BAY, OR	112,038
CLARENCE STRAIT, AK	87,906
SUMNER STRAIT, AK	77,851
PORT OF ASTORIA, OR	75,507
WRANGELL NARROWS, AK	73,051
HOUSATONIC RIVER, CT	69,166
CHATHAM STRAIT, AK	55,807
CROSS RIP SHOALS, NANTUCKET SOUND, MA	46,911
WOODS HOLE CHANNEL, MA	38,776
ST. MARYS RIVER, MI	37,102
SERGIUS AND WHITESTONE NARROWS, AK	22,746
NARROWS OF LAKE CHAMPLAIN, NY AND VT	20,148
GRAYS HARBOR AND CHEHALIS RIVER, WA	18,457

*Note: Fast Waterways routinely have currents above 1 knot.

Sub Total Oil Transported On Fast Waters	**650,667,337**
[Minus] NEWARK BAY, NJ (INCLUDED IN NEW YORK PORT)	-5,571,527
Total Oil Transported On Fast US Waters (tons)	**645,095,810**
Percent of Oil Transported on Fast Waters	**69%**

NEW LONDON HARBOR, CT	832,957
PANAMA CITY HARBOR, FL	789,685
PALM BEACH HARBOR, FL	788,391
WEEDON ISLAND, FL	784,105
FALL RIVER HARBOR, MA	781,522
ST. JOHNS RIVER, FL JACKSONVILLE TO LAKE HARNEY	775,445
ANCHORAGE, AK	751,208
INTRACOASTAL WATERWAY, JACKSONVILLE TO MIAMI, FL	706,676
MERMENTAU RIVER, LA	695,533
LAKE ERIE, INCLUDING UPPER NIAGARA RIVER	693,025
PASSIAC RIVER NJ	690,429
GREENVILLE, MS	689,861
SEARSPORT HARBOR, ME	688,028
ATLANTIC INTRACOASTAL WATERWAY (ST JOHNS TO NORFOLK)	678,829
CHRISTIANSTED HARBOR, ST. CROIX, VI	664,393
TRIBUTARY ARROYO COLORADO, TX	656,893
JOHNSONS BAYOU, LA	643,627
PENSACOLA HARBOR, FL	636,999
WICOMICO RIVER, MD (EASTERN SHORE)	635,974
INTRACOASTAL WATERWAY, FL (CALOOSAHATCHEE TO ANCLOTE)	614,424
PORT ANGELES HARBOR, WA	612,399
CONNECTICUT RIVER BELOW HARTFORD, CT	603,842
HOUMA NAVIGATION CANAL, LA	599,109
OKEECHOBEE WATERWAY, FL	590,991
MERMENTAU RIVER, BAYOUS NEZPIQUE AND DES CANNES, LA	561,329
SALEM HARBOR, MA	558,099
BAYOU LITTLE CAILLOU, LA	549,007
SAN BERNARD RIVER, TX	543,216
BAYOU TECHE AND VERMILION RIVER, LA	543,046
JAMES RIVER, VA (CONSOLIDATED REPORT)	512,492
OYSTER BAY, NY	509,328
GULF VIA BAPTISTI COLLETTE BAYOU	485,566
DETROIT RIVER, MI	469,261
LAKE HURON	461,899
ST. CLAIR RIVER, MI	457,944
HEMPSTEAD HARBOR, NY	422,575
BAYOU TECHE, LA	363,165
KAHULUI HARBOR, MAUI, HI	358,389
ST. THOMAS HARBOR, VI	332,257
INTRACOASTAL WATERWAY, MIAMI TO KEY WEST, FL	331,494
LAKE ONTARIO, INCLUDING LOWER NIAGARA RIVER	325,790
NORWALK HARBOR, CT	317,551
BILOXI HARBOR, MS	302,417
PETIT ANSE, TIGRE AND CARLIN BAYOUS, LA	294,930
HUMBOLDT HARBOR AND BAY, CA	291,141
HILO HARBOR, HI	286,059
NEW BEDFORD AND FAIRHAVEN HARBOR, MA	285,213
STAMFORD HARBOR, CT	266,286
SAN DIEGO HARBOR, CA	255,112
THAMES RIVER, CT	248,406
LITTLE RIVER, LA	230,023
MATAGORDA SHIP CHANNEL, TX	220,642
ST. LAWRENCE RIVER, US/CANADA	218,812
REVILLAGIGADO CHANNEL, AK	212,495
ST. MARKS RIVER, FL	208,409
CAPE FEAR RIVER ABOVE WILMINGTON, NC	205,738
UNALASKA BAY AND ISLAND, AK	204,687
PORT OF VANCOUVER, WA	191,519
EAST ROCKAWAY INLET NY	188,867
BARATARIA BAY WATERWAY, LA	187,718
NANTICOKE RIVER, DE AND MD	186,219
NEWPORT HARBOR, RI	185,778
MOREHEAD CITY HARBOR, NC	185,475
BRUNSWICK HARBOR, GA	185,393
BAYOU TERREBONNE, LA	182,237
WASHINGTON HARBOR, DC	177,791
COLORADO RIVER AND FLOOD DISCHARGE CHANNELS, TX	169,612
ICY STRAIT, AK	165,464
FRESHWATER BAYOU, LA	161,049
LYNN CANAL, AK	144,898

PORT OF LONGVIEW, WA	142,950
SKAGWAY HARBOR, AK	142,201
BIG PIGEON AND LITTLE PIGEON BAYOUS, LA	140,058
BELLINGHAM BAY AND HARBOR, WA	134,608
BAYOU DUPRE, LA	131,440
NORTHEAST (CAPE FEAR) RIVER, NC	127,969
OREGON SLOUGH (NORTH PORTLAND HARBOR), OR	125,426
FAJARDO HARBOR, PR	122,405
ORANGE, TX (SABINE RIVER)	121,546
RICE CREEK, FL	120,844
NEWPORT NEWS, VA	119,679
COOS BAY, OR	112,038
GUNTERSVILLE, AL	105,096
ALABAMA-COOSA RIVERS, AL AND GA	103,431
OSWEGO HARBOR, NY	103,340
NEUSE RIVER, NC	93,740
KODIAK HARBOR, AK	91,447
HOMER, AK	88,295
CLARENCE STRAIT, AK	87,906
FREDERICK SOUND, AK	85,170
SAN JOAQUIN RIVER, CA (INCLUDING PORT OF STOCKTON)	85,108
SUMNER STRAIT, AK	77,851
PORT OF ASTORIA, OR	75,507
FERNANDINA HARBOR, FL	73,965
WRANGELL NARROWS, AK	73,051
PORT HUENEME, CA	72,283
PONCE HARBOR, PR	71,269
LAKE SUPERIOR	70,747
TONGASS NARROWS, AK	69,322
HOUSATONIC RIVER, CT	69,166
MAYAGUEZ HARBOR, PR	68,320
PAMUNKEY RIVER, VA	68,010
LAKE PONTCHARTRAIN, LA	66,043
ST. MARYS RIVER, GA AND FL	60,938
STEPHENS PASSAGE, AK	60,252
PATUXENT RIVER, MD	58,261
CHATHAM STRAIT, AK	55,807
GULF COUNTY CANAL, FL	49,713
PORT ST. JOE HARBOR, FL	49,713
JUNEAU HARBOR, AK	49,458
HARBOR OF REFUGE, NANTUCKET, MA	47,490
CROSS RIP SHOALS, NANTUCKET SOUND, MA	46,911
KEY WEST HARBOR, FL	45,870
WOODS HOLE CHANNEL, MA	38,776
ST. MARYS RIVER, MI	37,102
PORT TOWNSEND HARBOR, WA	36,222
PASS MANCHAC, LA	35,999
LITTLE RIVER (CREEK), VA	35,417
APALACHICOLA, CHATTAHOOCHEE & FLINT RIVERS, GA AND FL	33,585
VINEYARD HAVEN HARBOR, MA	31,306
BETHEL HARBOR, AK	24,041
SERGIUS AND WHITESTONE NARROWS, AK	22,746
WHITTIER HARBOR, AK	21,534
SACRAMENTO RIVER, CA	20,762
NARROWS OF LAKE CHAMPLAIN, NY AND VT	20,148
ROANOKE RIVER, NC	19,414
ARECIBO HARBOR, PR	19,176
NOME, AK	18,467
GRAYS HARBOR AND CHEHALIS RIVER, WA	18,457
NAWILIWILI HARBOR, KAUAI, HI	17,672
SITKA HARBOR, AK	16,402
KAWAIHAE HARBOR, HI	14,533
GULFPORT HARBOR, MS	13,909
PORT OF KALAMA, WA	12,577
PAMLICO AND TAR RIVERS, NC	11,895
ST. PETERSBURG HARBOR, FL	10,866
ONANCOCK RIVER, VA	10,711

Total Oil Transported On All US Waterways (tons) 930,965,579

APPENDIX G USCG Facility Response Plans Information

The Worst Case Discharge (WCD) is defined by the Coast Guard in 33 CFR Parts 150 and 154 as:

$$WCD = ((TD + TI) * MF) + LV \qquad \text{(G-1)}$$

Where,
TD = time to discover
TI = time to isolate
MF = maximum flow rate
LV = total line drainage volume

It is the total amount of oil spilled, from the start of the spill, to the point at which all lines and tanks are secured, plus any oil in the drainage lines.

Facility Response Plans rate the threat of a facility as either Substantial Harm (SH) or Significant and Substantial Harm (S&SH). Substantial Harm covers mobile facilities, whereas, Significant and Substantial Harm covers fixed facilities. Facilities rated as Substantial Harm generally contain very low volumes of oil, 8,500 gallons on the average, and facilities rated as Significant and Substantial Harm contain higher volumes of oil, 6,300,000 gallons on the average. The threat assessment included facilities classified in both categories.

Not all US waterbodies are covered in the threat assessment, but rather, a sampling of twelve commercially active ones. This collection covers 234 facilities, with an average WCD of 4,600,000 gallons per facility. A complete listing is of the sample provided below in Table G-1 that included facilities, locations, WCDs and the facilities' respective waterbodies.

Table G-1. Representative Facility Response Plan Worst Case Discharge Threats by Waterway

Threatened Waterbody	Worst Case Discharge (gal)	Facility Name	City	State	Threat*
Aransas Pass	17,304	Tersoro Marine Services, Inc.	Aransas Pass	Texas	S&SH
Arkansas River	6,349,770	Frontier Terminal and Trading Co.	Catoosa	Oklahoma	S&SH
Arkansas River	5,796,000	Frontier Terminal	Muskegee	Oklahoma	S&SH
Arkansas River	3,254,286	Petroleum Fuel and Terminal Inc.	Pine Bluff	Arkansas	S&SH
Arkansas River	2,570,400	Safety Kleen	Little Rock	Arkansas	S&SH
Arkansas River	1,050,000	Arkansas Electric Cooperative	Ozark	Arkansas	S&SH
Arkansas River	646,800	Koch Materials Co.	Muskegee	Oklahoma	S&SH
Arkansas River	39,984	Frost Oil Co.	Van Buren	Arkansas	S&SH
Boca Grande Pass	7,560,000	Florida Power & Light - BOAC Grande	BOAC Grande	Florida	S&SH
Caloosahatchee River	7,560,000	Florida Power & Light - Fort Myers	Fort Myers	Florida	S&SH
Cooper River	26,715,204	Defense Fuels	Hanahan	South Carolina	S&SH
Cooper River	6,100,542	Armada Hess Corporation	N. Charleston	South Carolina	S&SH
Cooper River	3,167,954	Marathon Ashland Petroleum	Charleston	South Carolina	S&SH

Threatened Waterbody	Worst Case Discharge (gal)	Facility Name	City	State	Threat*
Cooper River	396,774	Allied Terminals, Inc.	Charleston	South Carolina	S&SH
Cooper River	390,600	Chevron USA	Charleston	South Carolina	S&SH
Cooper River	373,380	Shipyard River Coal Terminal	Charleston	South Carolina	S&SH
Cooper River	137,718	Charleston Lubricant Plants	N. Charleston	South Carolina	S&SH
Corpus Christi Channel	12,306	Tersoro Marine Services, Inc.	Aransas Pass	Texas	S&SH
Cumberland River	210,000,000	Gallatin Fossil Plant	Gallatin	Texas	S&SH
Cumberland River	150,016,188	Ashland Oil Co.	Nashville	Tennessee	S&SH
Cumberland River	97,361,502	Ashland Oil Co.	Nashville	Tennessee	S&SH
Cumberland River	1,986,096	Southern States Asphalt	Kuttawa	Kentucky	S&SH
Cumberland River	315,000	Kimbro Oil Co.	Nashville	Tennessee	SH[2]
Fore River	1,302,000	Portland Pipe Line Corp.	South Portland	Maine	S&SH
Fore River	1,081,206	Star Enterprise	South Portland	Maine	S&SH
Fore River	766,080	Sprague Energy Corp.	South Portland	Maine	S&SH
Fore River	420,000	Mobil Oil South Portland Terminal	South Portland	Maine	S&SH
Fore River	297,276	Koch Fuels	South Portland	Maine	S&SH
Fore River	209,916	Gulf Oil Limited Partnership	South Portland	Maine	S&SH
Fore River	156,282	Mason Station	Wiscasset	Maine	S&SH
Hillsborough Bay	6,300,000	Amerada Hess Corp	Port Tampa	Florida	S&SH
Hillsborough Bay	4,200,000	Murphy Oil U.S.A.	Port Tampa	Florida	S&SH
Hillsborough Bay	3,360,000	TECO - Hookers Point Station	Port Tampa	Florida	S&SH
Hillsborough Bay	3,318,000	E.A. Mariani (Asphalt)	Port Tampa	Florida	S&SH
Hillsborough Bay	3,150,000	Marathon Oil Co. (Light Oil)	Port Tampa	Florida	S&SH
Hillsborough Bay	3,024,000	TECO - Gannon Station	Port Sutton	Florida	S&SH
Hillsborough Bay	1,890,000	Martin Gas	Port Sutton	Florida	S&SH
Hillsborough Bay	1,428,000	Marathon Oil Co. (Asphalt)	Port Sutton	Florida	S&SH
Hillsborough Bay	1,008,000	Petroleum Packers	Port Tampa	Florida	S&SH
Hillsborough Bay	235,200	Citgo Petroleum Corp.	Port Tampa	Florida	S&SH
Hillsborough Bay	224,280	Amoco Oil Co.	Port Tampa	Florida	S&SH
La Quinta Channel	8,895,978	Koch Pipeline Co.	Ingleside	Texas	S&SH
Long Island Sound	32,532,276	Ameracla Hess Groton	Groton	Connecticut	
Long Island Sound	11,508,000	Hoffman Fuel Stanford	Stanford	Connecticut	
Long Island Sound	6,762,000	CL&P Norwalk	South Norwalk	Connecticut	
Long Island Sound	2,374,848	Amerada Hess	Weathersfield	Connecticut	
Long Island Sound	969,360	Mobil Coldspring Harbor	Coldspring	New York	
Long Island Sound	961,884	Northeast Petroleum, New Haven	New Haven	Connecticut	
Long Island Sound	755,916	Tosco Port Jefferson	Riverhead	New York	
Long Island Sound	504,000	Bridgeport United Recycling	Bridgeport	Connecticut	
Long Island Sound	496,230	United Illuminating	Bridgeport	Connecticut	
Long Island Sound	488,827	Bridgeport United Recycling	Bridgeport	Connecticut	

Threatened Waterbody	Worst Case Discharge (gal)	Facility Name	City	State	Threat*
Long Island Sound	460,530	Lilco Northport	Northport	New York	
Long Island Sound	419,202	Gulf Oil Co.	New Haven	Connecticut	
Long Island Sound	403,200	Wyatt Energy, Inc	New Haven	Connecticut	
Long Island Sound	381,318	Getty Terminals	New Haven	Connecticut	
Long Island Sound	178,752	Sprague Energy	Stanford	Connecticut	
Long Island Sound	174,720	CL&P MOntville	Uncasville	Connecticut	
Long Island Sound	173,250	CL&P Middletown	Middletown	Connecticut	
Long Island Sound	173,040	CL&P Devon	Devon	Connecticut	
Long Island Sound	162,624	RAD Energy	Oceanside	New York	
Long Island Sound	136,080	Harborview Terminals	Bridgeport	Connecticut	
Long Island Sound	106,260	Devine Bros.	Norwalk	Connecticut	
Long Island Sound	103,488	Pratt & Whitney	Middletown	Connecticut	
Long Island Sound	99,750	Santa Fuel, Inc.	Bridgeport	Connecticut	
Long Island Sound	75,600	Consumers Petroleum	Bridgeport	Connecticut	
Long Island Sound	75,600	Consumers Petroleum	Bridgeport	Connecticut	
Long Island Sound	71,484	Tosco Port Jefferson	E.Setaucket	New York	
Long Island Sound	69,720	Pfizer Chemicals	Groton	Connecticut	
Long Island Sound	63,000	Q - River Terminal	New Haven	Connecticut	
Long Island Sound	50,736	Northeast Petroleum	Weathersfield	Connecticut	
Long Island Sound	47,628	Hoffman Fuel	Bridgeport	Connecticut	
Long Island Sound	38,262	Amercola Hess	New Haven	Connecticut	
Long Island Sound	18,480	Lilco Port Jefferson	Port Jefferson	New York	
Long Island Sound	17,220	Hi-Ho Petroleums	Bridgeport	Connecticut	
Long Island Sound	15,750	Lilco E.F. Barrett Power Sta.	Island Park	New York	
Long Island Sound	4,074	Commander Oil Corp	Oyster Bay	New York	
Mississippi River	3,389,400	Entergy	Helena	Arkansas	S&SH
Mississippi River	1,260,000	Lion Oil	Memphis	Tennessee	S&SH
Mississippi River	276,948	Exxon	Memphis	Tennessee	S&SH
Mississippi River	211,512	Truman Arnold West Memphis	West Memphis	Arkansas	S&SH
Mississippi River	134,484	Blytheville River Rail	Blytheville	Arkansas	S&SH
Mississippi River	57,540	Coastal Unilube	West Memphis	Tennessee	S&SH
Mississippi River	56,028	Transmontaigne Terminal Co.	Arkansas City	Arkansas	S&SH
Mississippi River	53,928	Jantran Inc.	Rosedale	Mississippi	S&SH
Mississippi River	25,200	Texas Eastern Products Pipeline	Helena	Arkansas	S&SH
Mississippi River	3,822	American Commercial Liquid Terminal	Memphis	Tennessee	S&SH
Mississippi River	3,654	Conoco	Memphis	Tennessee	S&SH
Mississippi River	3,486	Southeast Transportation	Pine Bluff	Arkansas	SH
Mississippi River (lower)	2,100,000	Koch Asphalt	New Madrid	Missouri	
Mississippi River (upper)	162,078	Transmontiagne	Cape Girardeau	Missouri	S&SH
Mississippi River (upper)	9,492	Kidd Oil	Cape Girardeau	Missouri	SH
Ohio River	42,000,000	Ben's Run Natural Gas Terminal		West Virginia	S&SH
Ohio River	19,950,000	Century Oil			S&SH
Ohio River	8,722,686	Map/LLC Asphalt	Louisville	Kentucky	S&SH

Threatened Waterbody	Worst Case Discharge (gal)	Facility Name	City	State	Threat*
Ohio River	3,360,000	Map/LLC Clarksville	Louisville	Kentucky	S&SH
Ohio River	3,360,000	Henderson Terminaling Co.	Henderson	Kentucky	S&SH
Ohio River	3,284,400	Chevron USA	Louisville	Kentucky	S&SH
Ohio River	3,014,970	Zimmer Power Station	Moscow	Ohio	S&SH
Ohio River	2,545,116	Sun Oil	Louisville	Kentucky	S&SH
Ohio River	2,520,000	Transmontaigne Owensboro	Owensboro	Kentucky	S&SH
Ohio River	2,115,750	Beckford Pwr Station	New Richmond	Ohio	S&SH
Ohio River	2,100,000	Pennzoil Co.	Charleston	West Virginia	S&SH
Ohio River	1,920,786	Bunge Corp	Cairo	Illinois	S&SH
Ohio River	1,800,162	Map/LLC Asphalt	Louisville	Kentucky	S&SH
Ohio River	1,680,000	Shell Oil (Asphalt)	Cincinnati	Ohio	S&SH
Ohio River	1,260,000	Degussa Carbon Black Corp.	Belpre	Ohio	S&SH
Ohio River	1,218,840	Shell Chemical Co.			S&SH
Ohio River	1,176,000	General Gavin Power Plant			S&SH
Ohio River	1,008,000	Mountaineer Power Plant		West Virginia	S&SH
Ohio River	840,000	Map/LLC Evansville	Evansville	Indiana	S&SH
Ohio River	823,200	Transmontaigne Evansville	Evansville	Indiana	S&SH
Ohio River	799,974	Map/LLC Louisville	Louisville	Kentucky	S&SH
Ohio River	664,020	Go-Mart Inc.			S&SH
Ohio River	630,000	Map/LLC Mt. Vernon	Mt. Vernon	Indiana	S&SH
Ohio River	519,960	Koch Materials	North Bend	Ohio	S&SH
Ohio River	268,926	N&S Railroad Corp.			S&SH
Ohio River	268,800	Transmontaigne Louisville	Louisville	Kentucky	S&SH
Ohio River	258,510	Marathon Ashland	Marietta	Ohio	S&SH
Ohio River	246,960	Consolidated Grain and Barge	Mt. Vernon	Indiana	S&SH
Ohio River	126,000	Safety Kleen			S&SH
Ohio River	110,880	St. Mary's Refinery		West Virginia	S&SH
Ohio River	98,280	Markwest Hydrocarbon			S&SH
Ohio River	95,760	BP Oil Co.	Bromely	Kentucky	S&SH
Ohio River	95,760	Marathon/Ashland Co.	Covington	Kentucky	S&SH
Ohio River	95,760	Marathon//Ashland (Asphalt)	North Bend	Ohio	S&SH
Ohio River	74,970	American Electric Power	Rockport	Indiana	S&SH
Ohio River	67,242	Countymark Corp.	Mt. Vernon	Indiana	S&SH
Ohio River	56,742	Dayton Power and Light	Manchester	Ohio	S&SH
Ohio River	50,904	Koch Materials, Inc.			S&SH
Ohio River	50,904	Itapco Inc	Parkersburg	West Virginia	S&SH
Ohio River	50,400	Transmontaigne Kentuckiana	Louisville	Kentucky	S&SH
Ohio River	50,400	BP Gulf Oil	Louisville	Kentucky	S&SH
Ohio River	50,400	Citgo Petroleum, Co.	Louisville	Kentucky	S&SH
Ohio River	48,342	Exxon Co. USA			S&SH
Ohio River	43,134	Asphalt Materials Inc.			S&SH
Ohio River	39,564	Itapco, Inc.	Marietta	Ohio	S&SH
Ohio River	30,870	BP Oil			S&SH
Ohio River	28,686	Transmon. Terminals	Covington	Kentucky	S&SH
Ohio River	26,334	Baker Oil			S&SH
Ohio River	23,310	John E. Amos Power Plant			S&SH
Ohio River	22,554	GE Mt. Vernon	Mt. Vernon	Indiana	S&SH

Threatened Waterbody	Worst Case Discharge (gal)	Facility Name	City	State	Threat*
Ohio River	18,900	Allied Signal Inc.			S&SH
Ohio River	17,178	Transmontaigne Henderson	Henderson	Kentucky	S&SH
Ohio River	14,406	Owensboro Grain	Owensboro	Kentucky	S&SH
Ohio River	13,860	Marathon Ashland Finished Product Dock		Kentucky	S&SH
Ohio River	13,860	Marathon Ashland Refinery-Crude Oil Dock			S&SH
Ohio River	12,474	Middleport Terminal Inc.		Ohio	S&SH
Ohio River	11,340	Marathon Ashland Repair Terminal		Kentucky	S&SH
Ohio River	11,004	Ohio Oil Gathering Corp.		Ohio	S&SH
Ohio River	9,618	Southern States	Owensboro	Kentucky	S&SH
Ohio River	9,492	Bruce Miller Oil Co.	Aurora	Indiana	SH
Ohio River	9,492	Clean Harbors	Cincinnati	Ohio	SH
Ohio River	9,492	Lykins Oil Co. Inc.	Monroe	Ohio	SH
Ohio River	9,240	Jones Oil Co.	Shoals	Indiana	SH
Ohio River	8,484	Halzit	Covington	Kentucky	SH
Ohio River	8,484	McRussel	Maysville	Kentucky	SH
Ohio River	8,484	Paragon	Cincinnati	Ohio	SH
Ohio River	8,274	Queens City Terminal	Cincinnati	Ohio	S&SH
Ohio River	8,148	Kentucky Marine Corp.	Ledbetter	Kentucky	S&SH
Ohio River	7,980	Louisiana Dock	Louisville	Kentucky	S&SH
Ohio River	7,980	Yeager Materials	Owensboro	Kentucky	SH
Ohio River	7,182	Morehead Marine Service	Hebron	Kentucky	SH
Ohio River	6,972	Kentucky Petroleum	Louisville	Kentucky	SH
Ohio River	6,762	Somerset Refinery	Somerset	Kentucky	SH
Ohio River	6,468	Usher Transportation	Louisville	Kentucky	SH
Ohio River	6,384	Madison Coal & Supply			S&SH
Ohio River	5,964	Wooten River Service	Louisville	Kentucky	SH
Ohio River	5,964	Art Services, Inc.	Louisville	Kentucky	SH
Ohio River	5,250	Westway Terminals	Cincinnati	Kentucky	S&SH
Ohio River	4,998	Heritage Remediation	Louisville	Kentucky	SH
Ohio River	4,242	McGinnis	Cincinnati	Ohio	SH
Ohio River	4,200	Citgo (Uno-Ven)	Cincinnati	Ohio	S&SH
Ohio River	3,990	Southside River Trail	Cincinnati	Ohio	S&SH
Ohio River	3,108	Miami Power Station	North Bend	Ohio	S&SH
Ohio River	2,982	Heritage Environmental Svc.	Cincinnati	Ohio	SH
Ohio River	2,352	River Transportation	Cincinnati	Ohio	S&SH
Ohio River	1,764	Environmental Enterprises	Cincinnati	Ohio	SH
Old Tampa Bay	10,500,000	Florida Power Co - Bartow	Weedon island	Florida	S&SH
Old Tampa Bay	672,000	Chevron U.S.A. Co.	Old Port Tampa	Florida	S&SH
Old Tampa Bay	420,000	Shell Oil Products	Old Port Tampa	Florida	S&SH
Ouachita R.	756,000	Cross Oil	Smackover	Arkansas	S&SH
Tampa Bay	21,000,000	Florida Power & Light - Port Manatee	Port Manatee	Florida	S&SH
Tampa Bay	4,200,000	TECO- Big Bend Station	Apollo Beach	Florida	S&SH
Tampa Bay	1,050,000	Florida Power Corp. - Bayboro	Bayboro Harbor	Florida	S&SH
Tampa Bay	1,050,000	GATX Terminals Corp.	Port Tampa	Florida	S&SH
Tampa Bay	462,000	Coastal Fuels, Inc.	Port Manatee	Florida	S&SH

Threatened Waterbody	Worst Case Discharge (gal)	Facility Name	City	State	Threat*
Tampa Bay	420,000	Egmont Key Pilot Station	Egmont Key	Florida	S&SH
Tampa Bay	357,000	Louis Dreyfuss Energy	Port Tampa	Florida	S&SH
Tampa Bay	21,000	Coastal Fuels (Port Everglades)	Miami	Florida	SH
Tampa Bay	19,992	Environmental Recovery, Inc.	Jacksonville	Florida	SH
Tampa Bay	19,992	Souther Waste Services (SWS)	St. Petersburg	Florida	SH
Tampa Bay	9,492	Central Oil	Tampa	Florida	SH
Tampa Bay	9,408	Port Petroleum, Inc.	Miami	Florida	SH
Tampa Bay	9,240	Sitton Transportation Corp.	Tampa	Florida	SH
Tampa Bay	8,400	Tampa Bay Marine Services	Tampa	Florida	SH
Tampa Bay	7,980	Cape Canaveral Marine Ser.	Tampa	Florida	SH
Tampa Bay	7,518	Ward Oil Co.	Tampa	Florida	SH
Tampa Bay	7,392	Parker Fuel Co.	Tampa	Florida	SH
Tampa Bay	7,224	Tropic Oil Co.	Miami	Florida	SH
Tampa Bay	7,182	Radiant Oil Co.	Tampa	Florida	SH
Tampa Bay	6,510	Spartan Oil Co	Tampa	Florida	SH
Tampa Bay	5,964	A & A Coastal	Tampa	Florida	SH
Tampa Bay	4,788	Florida Waste Envir. Services	Tampa	Florida	SH
Tampa Bay	4,284	Oil Recovery Co.	Mobile	Florida	SH
Tennessee River	126,000,000	Colbert Fossil Plant	Tuscumbia	Alabama	S&SH
Tennessee River	83,437,200	Ashland Oil Co.	Knoxville	Tennessee	S&SH
Tennessee River	27,293,154	Marathon Ashland, Inc.	Paducah	Kentucky	S&SH
Tennessee River	19,866,000	Cargill	Guntersville	Alabama	S&SH
Tennessee River	5,000,016	New Johnsonville Fossil Plant	New Johnsonville	Tennessee	S&SH
Tennessee River	3,360,000	Ashland Oil Co.	Chattanooga	Tennessee	S&SH
Tennessee River	1,371,510	Amoco Oil Co.	Chattanooga	Tennessee	S&SH
Tennessee River	420,000	Amoco Oil Co.	Guntersville	Alabama	S&SH
Tennessee River	200,004	Port of Decatur	Decatur	Alabama	S&SH
Tennessee River	165,228	Transmontiagne	Paducah	Kentucky	S&SH
Tennessee River	126,840	Volunteer Asphalt	Knoxville	Tennessee	S&SH
Tennessee River	105,000	Mead Containerboard	Stevenson	Alabama	S&SH
Tennessee River	100,380	Koch Materials	Parsons	Tennessee	S&SH
Tennessee River	58,212	Murphy Oil Co.	Sheffield	Alabama	S&SH
Tennessee River	45,864	Transmontiagne	Paducah	Kentucky	S&SH
Tennessee River	42,924	Ergon Inc.	Jackson	Mississippi	S&SH
Tennessee River	32,844	Transmontiagne	Paducah	Kentucky	S&SH
Tennessee River	10,500	First Recovery	Paducah	Kentucky	SH
Tennessee River	9,198	Duke and Long Dist.	Paducah	Kentucky	SH
Tennessee River	8,988	Usher Transport, Inc.	Paducah	Kentucky	SH
Tennessee River	7,308	Bunge Corp.	Decatur	Alabama	S&SH
Tennessee River	4,788	Archer Daniels Midland	Chattanooga	Tennessee	S&SH
Tennessee River	3,948	Walker Boat Yard	Paducah	Kentucky	S&SH
Verdigris River	11,471,586	Total Petroleum	Catoosa	Oklahoma	S&SH
Verdigris River	3,024,000	Safety Kleen	Catoosa	Oklahoma	S&SH
Verdigris River	928,452	So. Missouri Oil Co.	Catoosa	Oklahoma	S&SH
	8,988	Knapp Oil	Xenia	Illinois	SH
	6,510	Martin Gas Transport	Kilgore	Texas	SH
	5,460	LWD	Calvert City	Kentucky	SH
Average Worst Case Discharge	4,597,667 Gallons				

* S&SH Significant and Substantial Harm
SH Substantial Harm

Appendix H Anatomy of Freshwater and Coastal Areas

Anatomy of Freshwater Areas[58]

Open Water

Open water areas on lårge lakes and bays, such as the Great Lakes, have ocean-like waves and current conditions. The currents on freshwater lakes and bays are generally less than one knot. Tidal and seiche actions do create cyclical ties. The exception to this would be near rivers that connect two different lakes that are at different elevations or choke points between open areas. Ice formation is common for inland lakes in the winter. The mouth of rivers often have sediments, debris, shallow areas and man made structures that complicate water circulation patterns. Most responses on lakes and open bays require the use of vessels to deploy protection and recovery equipment.

Environmental sensitivity of open water areas is generally low to medium because oil can be readily diluted and many organisms are mobile and, thus, can escape the oil. Protected areas of lakes are more sensitive due to their slower dilution rates. Birds are most vulnerable when landing on the water. Fish in early stages of development may be affected by oil in the water column while adult fish populations are generally not.

Large River

Large rivers usually have currents above one knot such as the Mississippi, Columbia, Hudson and Delaware Rivers and their major tributaries. They have meandering channels and sometimes locks and dams. Water levels and currents vary seasonally depending upon rain and snowmelts. Sometimes reversal flows go up tributaries and backwater lakes. Flood plains are common. Silt and sediment readily entrain in the turbulent water forming emulsions and mixing with the oil, sometimes causing oil to settle on the bottom. Brackish water and reversing tidal currents are common near coastal areas.

Environmental sensitivity is medium because they have extensive biological and recreational use although flushing rates are high. They are generally major transportation routes. Drinking, industrial and cooling water intakes are common and must be shut down when oil transits due to the high mixing and turbulence on these rivers. Under flood conditions, the flood plains are sensitive habitats that can be damaged by oil. High currents, islands, eddies, sand bars, debris and ice can complicate spill responses.

Small Rivers and Streams

Small rivers and streams are generally shallow with less than 6-foot depth. Water flow is seasonally variable. They are associated with fast flowing rapids with gravel banks and slow moving areas with muddy banks and vegetation. Debris often blocks sections of the river. Multiple channels are common. Boat access is usually limited. All these factors complicate response efforts. Oil spills are more likely due to pipeline ruptures, train derailments, highway accidents and shore facility releases.

They have high to medium sensitivity due to a greater range of habitats and lower dilution rates. Fish spawn in small rivers and streams. Adjacent flood plains have slow flushing rates. Spill can cause shutdown of water intakes for drinking water, farming and industrial use.

Vegetated Riverbanks

They consist of non-wetland vegetation such as grass, bushes, shrubs and trees prevalent to the adjacent land habitats. The banks are gentle and steep sloped. The soil is not water saturated and when it consists of gravel, it is more likely to be penetrated by oil than sand and clay. It is medium in sensitivity to oil because it does not generally have habitats for sensitive animals and plants. On mild slopes, oil is likely to form in pools and penetrate into the soil and coat larger vegetation areas.

Wetlands

Wetlands are generally low current areas characterized by vegetation that has adapted to wet conditions. These include marshes, bogs, bottom hardwood forests and swamps. These level backwater areas often have muddy sand rich in organic matter that promotes feeding grounds for birds and fish. They are usually vulnerable to oil spills during flood conditions from adjacent rivers and streams. They are highly sensitive due to habitat diversity, supporting many local plants and animals, and migratory birds. They are often the home of endangered species.

Manmade Structures

Piers, bulkheads, bridges, riprap structures, breakwaters and seawalls are typical man-made structures found in freshwater and coastal environments. Riprap structures have large voids that are susceptible to oil penetration while bulkheads and bridge abutments are not. Structures are often placed to prevent wave and current erosion of the bank. These structures can vary in sensitivity based upon the local environment, and animals and plants that have migrated into the area after construction. Usually they are aggressively cleaned after a spill due to their visibility and public use. It is desirable to keep oil out of breakwaters, riprap areas and from under piers because the oil will tend to become trapped. It will then continue to migrate out for long periods after the initial cleanup is completed.

Anatomy of Coastal Areas

Bays and Sounds

Bays and sounds are large semi-protected bodies of water formed in coastal areas. Examples include Prince William Sound, Puget Sound, Long Island Sound, Delaware Bay, San Francisco Bay, Chesapeake Bay and Mobile Bay. Tidal currents are present and many streams, rivers and harbors border these large bays. Sometimes many large islands are present that complicates circulation currents. As discussed earlier the natural period of these waterbodies can resonate and amplify regional tidal waves and associated tidal currents. Large waves can develop quite easily.

Harbors

Harbors and bays consist of large protected areas adjacent to the ocean. Waves can become significant if a large fetch is prevalent. Examples include Portsmouth, New Hampshire; New York, New York; Norfolk, Virginia; Charleston, South Carolina; Miami, Florida; Galveston, Texas; Corpus Christi, Texas; Portland, Oregon; Seattle, Washington and Valdez, Alaska. Man-made structures are frequent and population densities are high. Very often, rivers are flowing into or through the harbor area. Entrance areas are often constricted causing high currents during maximum ebb and flood tides. Reversing tidal currents make spill response difficult. Large open areas require vessel response. Sensitivities are medium to high depending upon the local environment and commerce significance. Salt marshes, connecting rivers and small inlets, if present, must be protected during flood tides.

Salt Marshes

Salt marshes are the most productive of aquatic environments. They have low currents and thus low flushing energy and rates. They are often protected by barrier islands with narrow inlets. This makes oil exclusion difficult due to the high tidal currents at these entrance areas. They are very sensitive to oil spills due to low dilution rates, a vast variety of habitats and associated plant and animal marine life. Salt marshes are breeding grounds for many invertebrates, fish and birds. High sedimentation rates often incorporate oil into the sediment. These areas should have high priority protection from oil entering because once contaminated, cleanup may do more harm than letting the oil naturally degrade.

Tidal inlets

Tidal inlets are the mouths of streams, rivers, salt marshes and constricted openings for harbors and bays. They are very often associated with fresh water runoff due to connected rivers and streams. Their relatively narrow inlet compared to the volume of water resident inside causes high currents through the inlet during the flood and ebb tides. Complex tidal flows are present due to eddies and circulation around deltas and sandbars near the inlets. This makes it very difficult to keep oil from entering from a coastal or nearby ocean spill. Sensitivity is medium to high depending upon the specific environment inside the inlet. Once oil enters the inlet, current velocities will slow

inside larger bays making oil containment easier. Outside the inlet, currents may be slower but waves are generally higher making oil containment more difficult. Diversion of oil around inlets during flood tides is desirable.

Straits

Straits are associated with navigation passages where landmasses converge and form small openings. Typically, these are located in large bays and sounds or coastal areas with many islands. Currents are generally high through straits due the volume of water passing through a narrow opening. They are associated with reversing tidal currents. Complex tidal flows and eddies can be generated around the straits. Moderate to high waves are found in coastal region straits. Environments vary in these areas, but generally, they are low to medium in sensitivity due to typical coastal sand and rocky shorelines. Navigation is sometimes difficult in restricted water, increasing the likelihood of collisions and groundings compared to open coastal areas.

APPENDIX I Cascade Booming

Procedures for Booming a Narrow River[59]

General information:

All three team leaders, the incident commander and the ferry system operator should have two-way radios for communications. All personnel shall have appropriate safety equipment that includes as a minimum: life jacket, hard hat, safety glasses, work gloves and steel toe rubber boots. Beware of lines under tension because they may part. Select mooring points that are strong. If available, the base of large trees and boulders should be used for boom anchor points. Use multiple anchors if required for the main upstream and downstream anchor points This procedure outlined can be used across waterways up to 600 feet wide. Wider waterways will require anchors in the water instead of all shoreline anchors as described below. For additional information on setup and deployment of cascade booming see Figures E-1 and E-2 below.

Team A Duties in Cascade Boom Deployment

Setting up for boom deployment:

Lay each boom section out along the shoreline. Leave a 10-foot overlap between each boom section.

The first boom should be closest to the water's edge with each succeeding boom laid on the inland side of the previous one.

Establish the main anchor point at the containment area. The first boom should be anchored here within 5 to 10 feet of the downstream end of the boom on shore and then entrenched in place after deployment. Shore sealing (water ballast) boom can also be used as the first boom, instead of entrenching, where tidal fluctuations are significant.

Place towing bridles and tie anchor lines onto the downstream end of each boom. Lay them along the shore while walking back to the main anchor point.

If any diagonal lines from the upstream end of the boom are crossed, be sure to weave your line under them.

If additional anchor points are needed, place them inland of the initial anchor point no more than 12 inches apart.

In some cases, you may want to put a second (safety) line on the downstream end of the boom. It will help keep the downstream end of the boom from slipping under the downstream boom. It can be secured anywhere on shore perpendicular to the boom.

Safety lines are generally run under the downstream anchor lines and forward "diagonal lines" are run over the upstream anchor "pull line".

During boom deployment:

The Team Leader should stand near the anchor line tie down point and listen to the Incident Commander. If any adjustments are needed in the line, Team Members should release or pull in while the Team Leader issues commands to adjust the boom properly.

Someone may also be needed to tend the safety line during deployment. Team A leader must be in a position so that Team Members and at both lines can hear them.

Team B Duties in Cascade Boom Deployment

Setting up for boom deployment:

Assist Team A in laying the boom sections along the shoreline leaving 10-foot overlap between them boom sections.

On the upstream end of each boom section, connect a towing bridle, buoy and two lines. One line will be long enough to go across the river to Team C. It is referred to as the "pull line." The other, "diagonal line" will be tended by Team B.

If any lines from the downstream end of the boom are crossed place the upstream lines over them.

The Team C pull line should be laid along the shoreline just as the boom is. Each succeeding line should be inland of the previous one. String the line upstream to the ferry system and then add enough rope to cover the distance across the river.

The diagonal line should be secured on the nearshore side about 30 to 50 feet upstream from the end of the boom. Be sure there is enough line to release the boom out into the water. Each succeeding boom will need additional line as more width of the river is boomed.

During boom deployment:

The B Team Leader should stand near the diagonal line tie down point listening to the incident commander. As adjustments are required in your line, Team Members should release or pull in as directed by the Team Leader.

Team C Duties in Cascade Boom Deployment

Setting up for boom deployment:

Team C is responsible for setting up the Ferry System and anchor points on the farshore side of the river for the pull lines of each boom.

The Ferry System is a set of three lines strung across the river and connected with a pulley. It is used for moving things across the river. It consists of a static line with a nearshore ferry line and a farshore ferry line attached to a pulley that runs rolls on the static line.

The static line must be strung across the river using a boat, bridge or line-throwing gun. If a line gun is used there must be a person on the farshore. The static line must be free of knots and strung tightly out of the water. If possible place the nearshore end of the static line upstream and higher than the farshore side. This will take advantage of gravity and the current forces when pulling the pull lines and boom across the river. Once the static line is across repeat the process to get the farshore ferry line across. The nearshore ferry line and the pulley can be attached on the nearshore side to complete the system. After the ferry system is complete all Team C members except one should go the farshore side. The ferry system operator on the nearshore side should have a two way radio or use a predetermined hand signal system for directions on when to send the pull line for each boom across the river.

When ready the Team Leaders should contact the Incident Commander. The Team C leader shall work with the Incident Commander to select the anchor point for the first boom. Succeeding anchor points for additional booms should be selected after the previous boom has been deployed.

During boom deployment:

Once the Incident Commander has indicated that he or she is ready to deploy a boom, then give the signal or command to the team members on the ferry line to release the ferry line with the boom's pull line.

Take the boom pull line off the ferry system and move it over to the anchor point and secure it. Then pull all of the slack out of the line. The Team C leader should them contact the incident commander to let them know that slack is out of the line. Then wait for the command form the Incident Commander to pull the boom into position. This will require a lot of effort. It is usually accomplished by pulling the line through the anchor system and down the shore adjacent to the pull line. Pulleys can be used to make it easier to take the final slack out of the boom.

Narrow River Booming Diagram

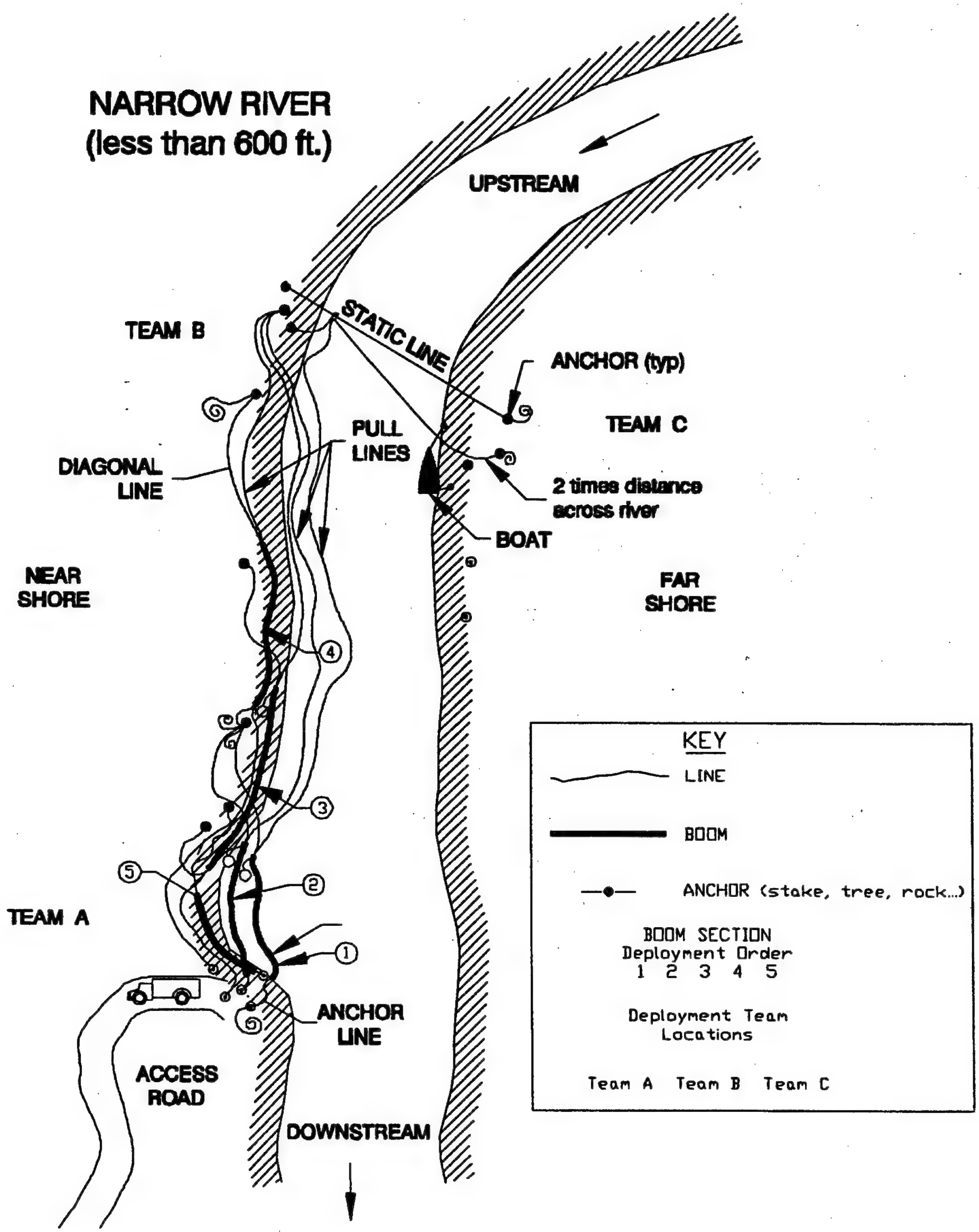


Figure I-1. Cascade Booming Setup (DOWCAR Technique)

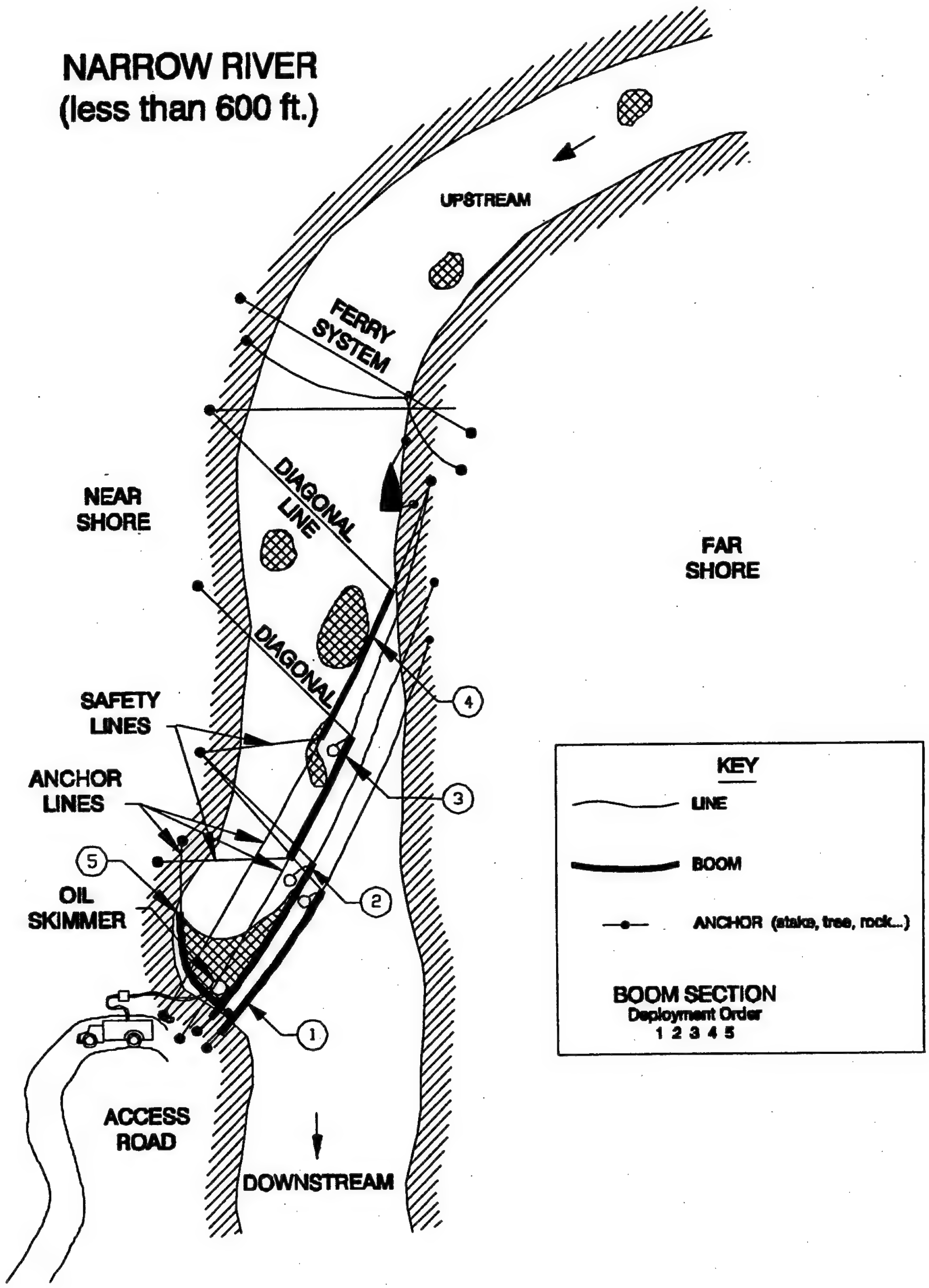


Figure I-2. Cascade Booming Deployed (DOWCAR Technique)

Coastal and Wide River Booming Diagram

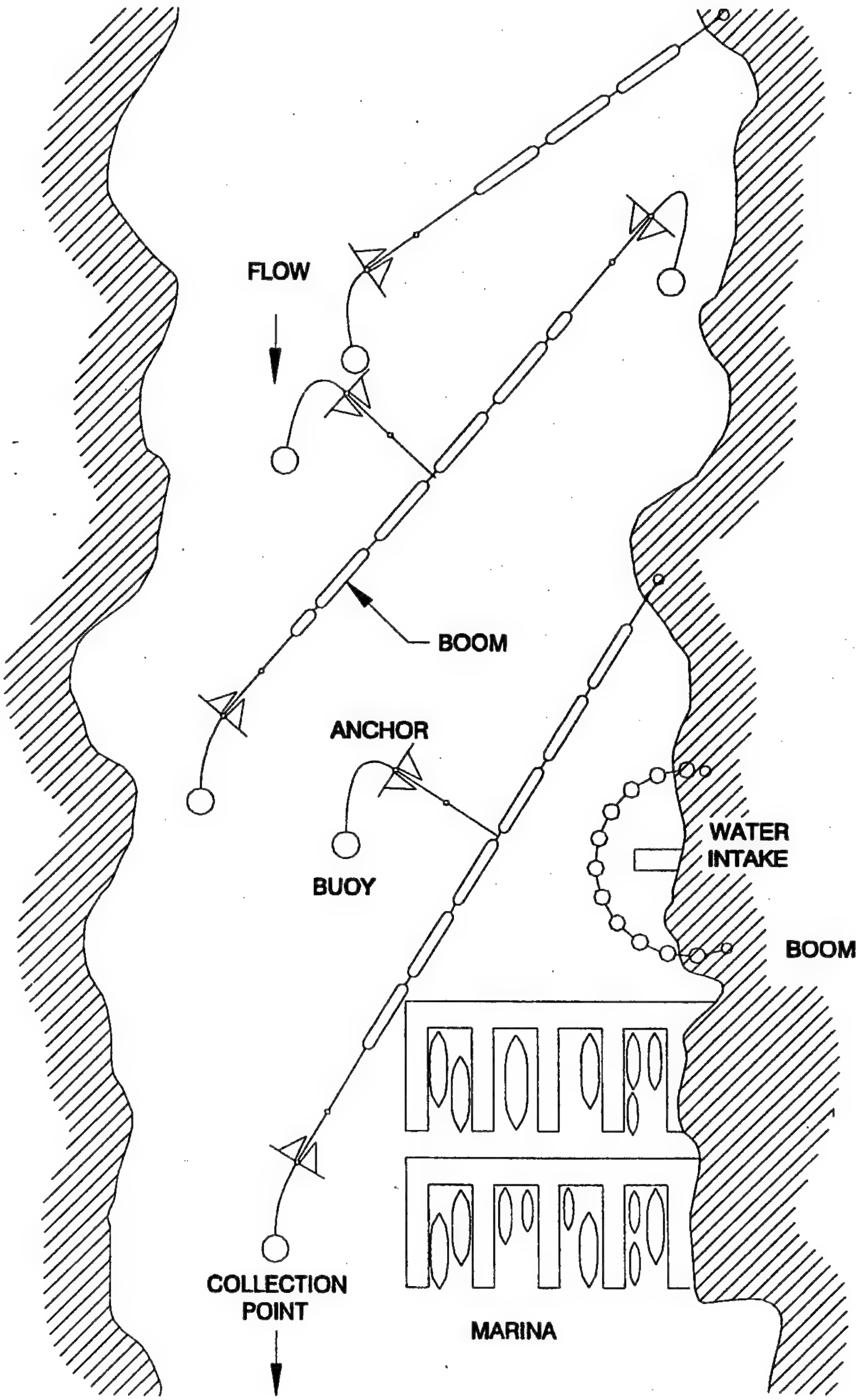


Figure I-3. Deflection and Exclusion Booming around Sensitive Areas

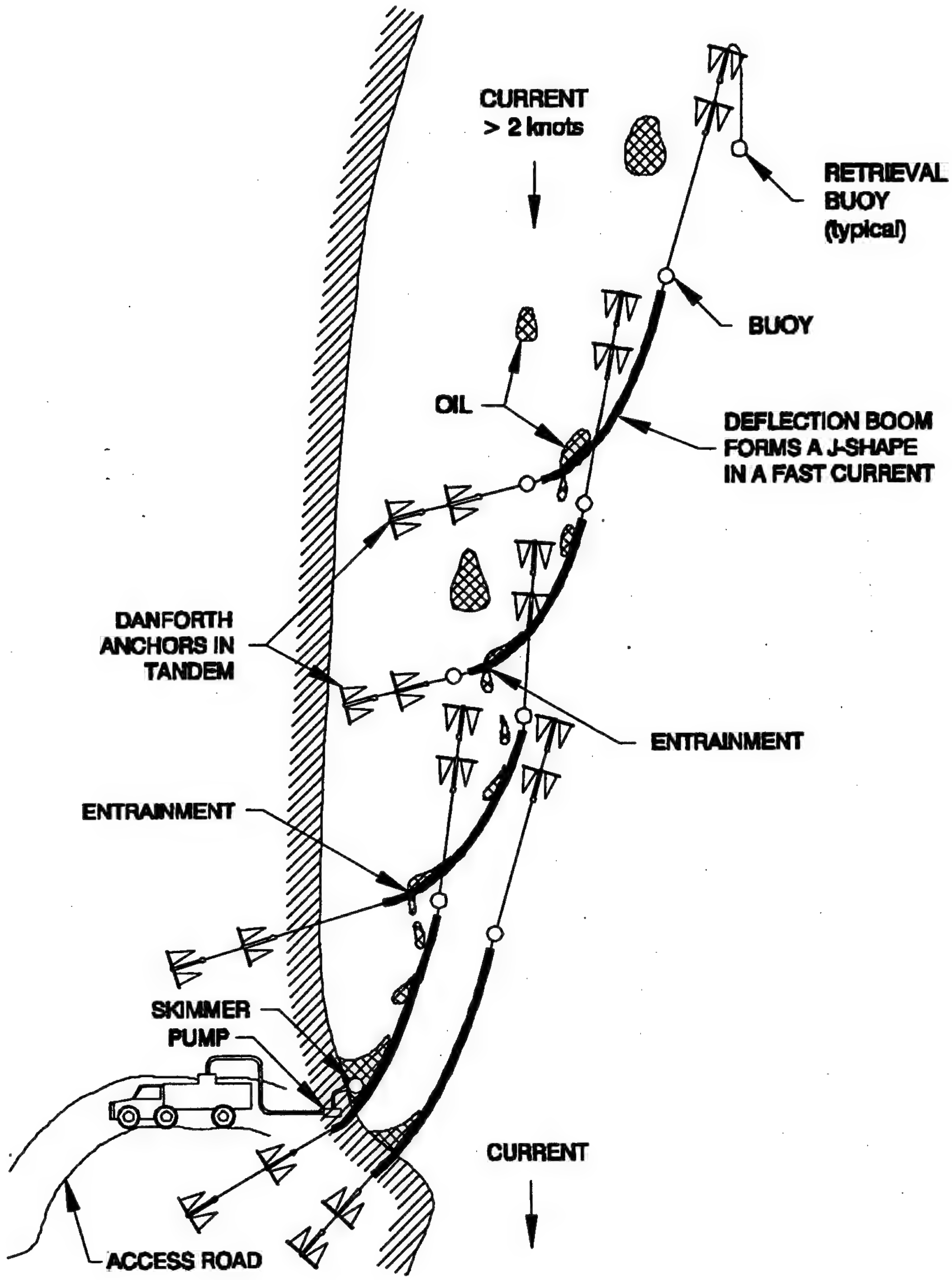


Figure I-4. Overlapping J Shape Booming Prevents Oil Loss due to Entrainment

APPENDIX J Continuous Deflection Booming Using Shoreline Tiebacks

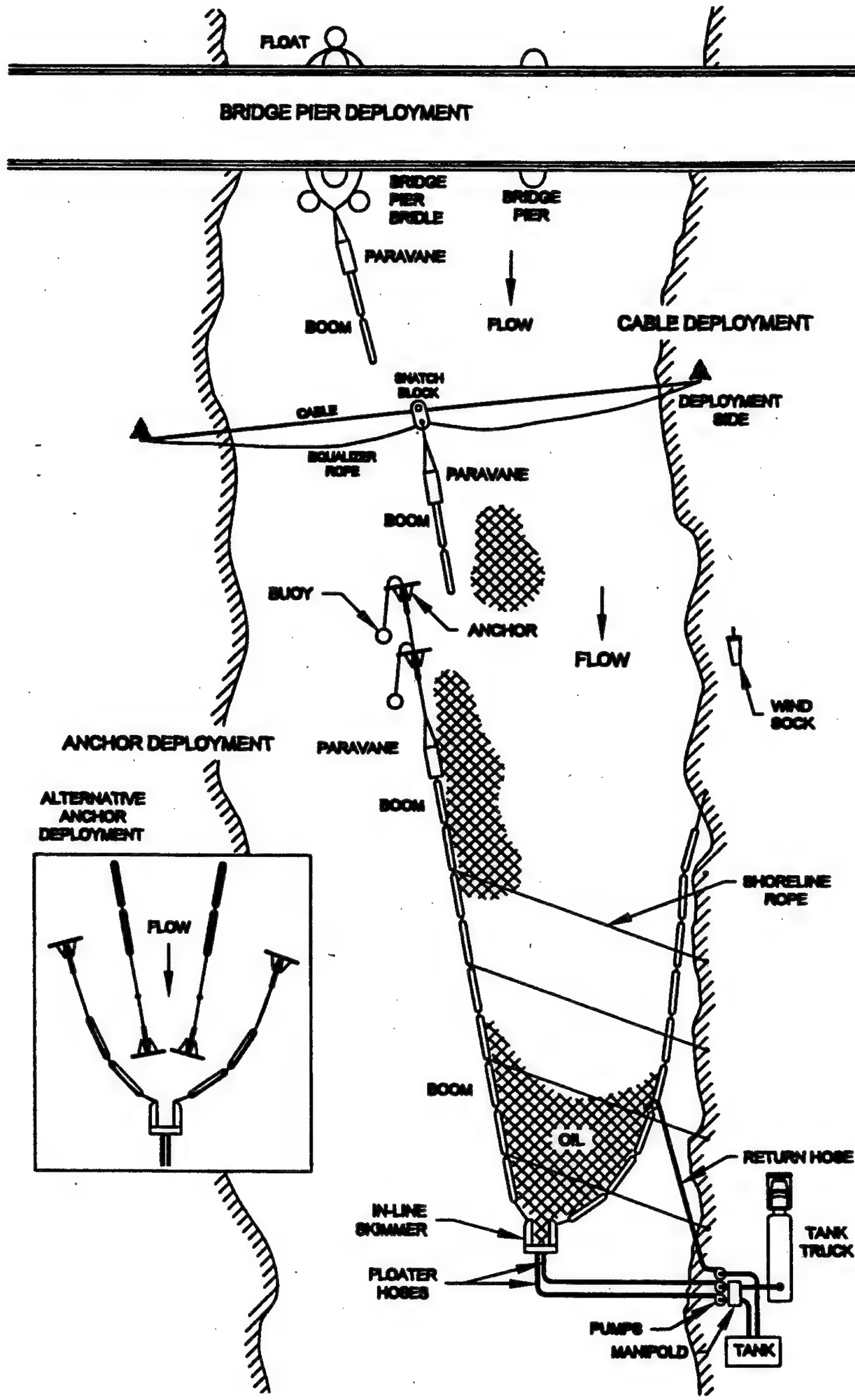


Figure J-1. Trans Mountain Pipeline Technique for Oil Containment on Rivers

APPENDIX K Boom Deflector Strategies

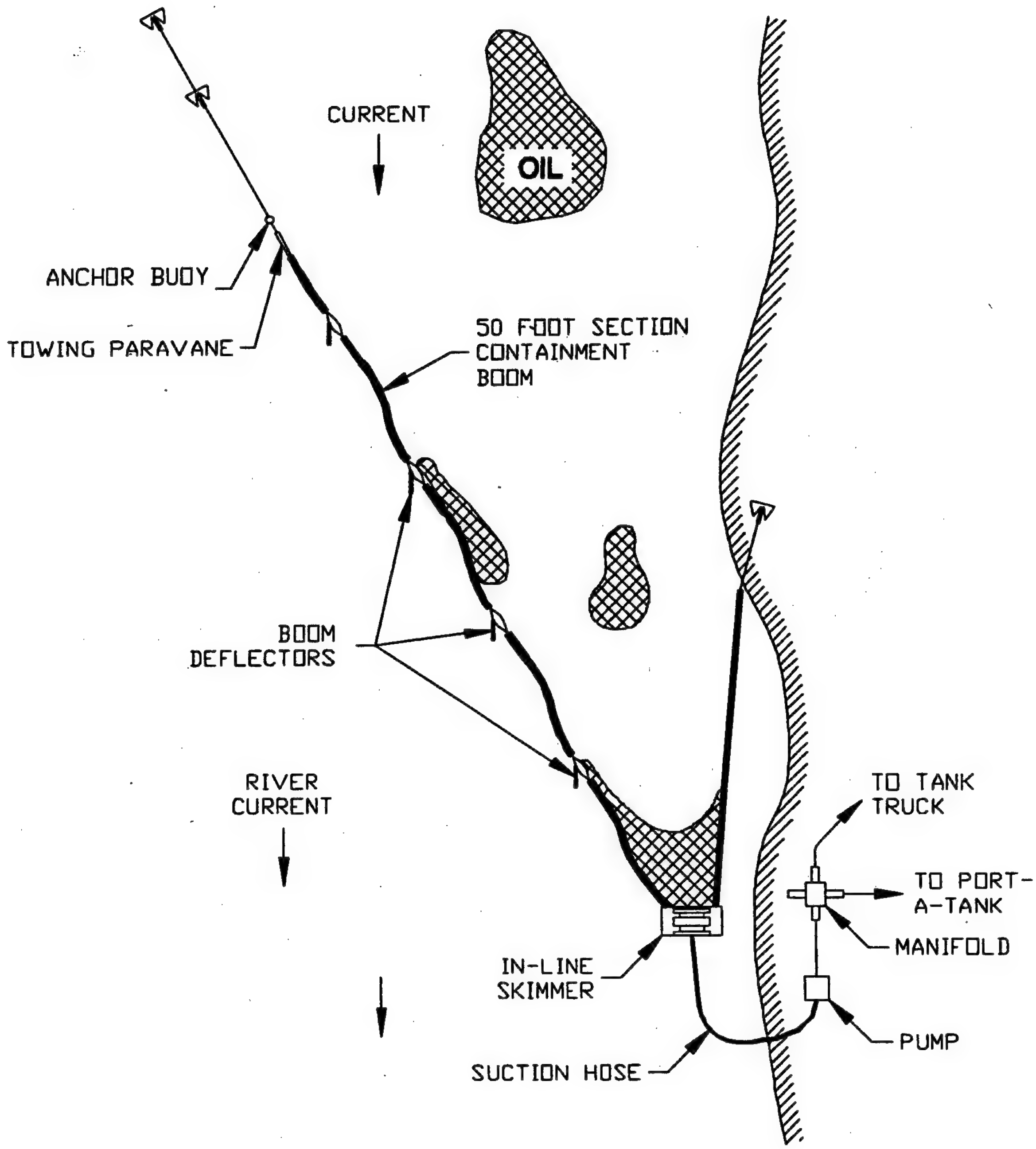


Figure K-1. Boom Deflectors Used in Wide River

APPENDIX L Current Rudder

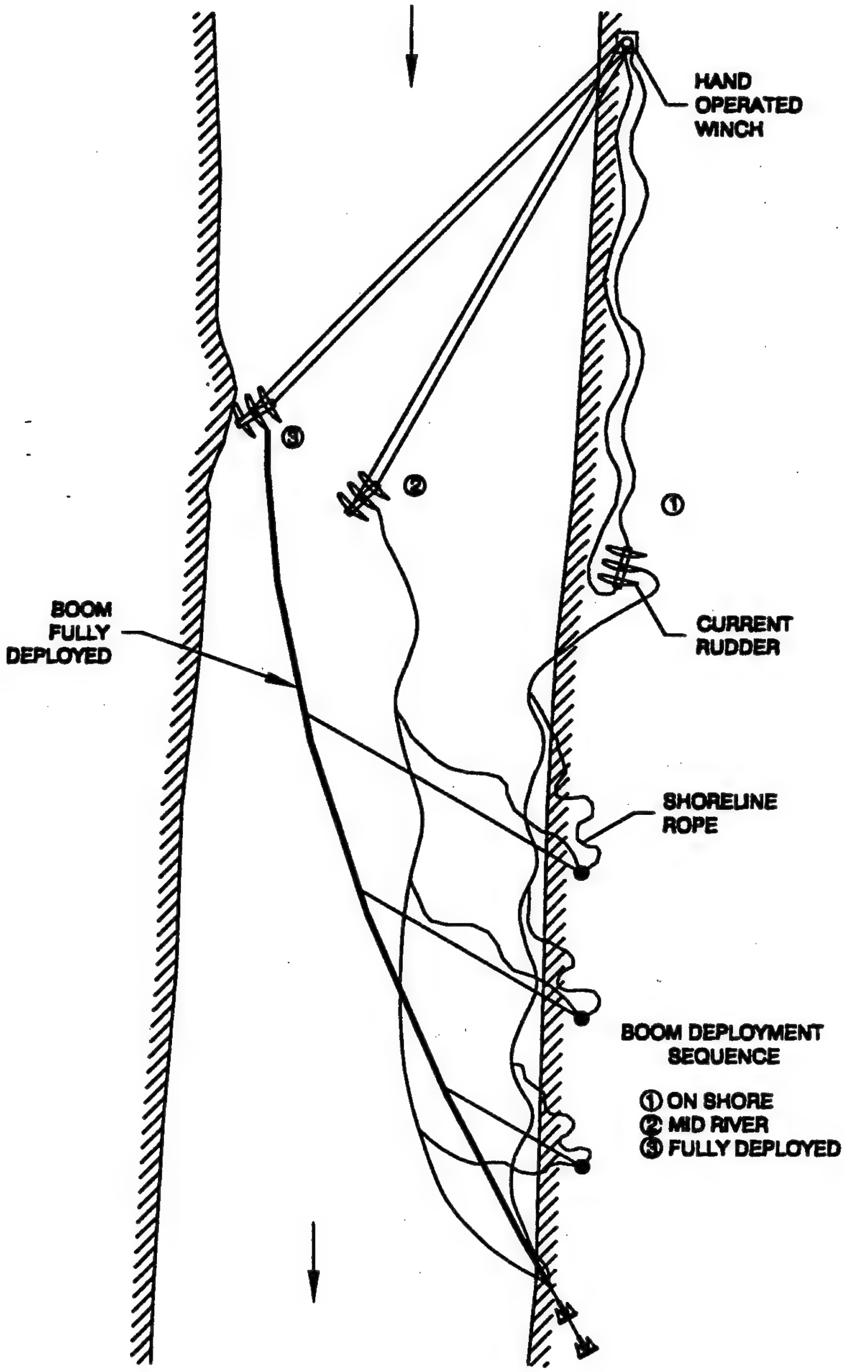


Figure L-1. Current Rudder Strategy for Navigable River

APPENDIX M Flow Diverters

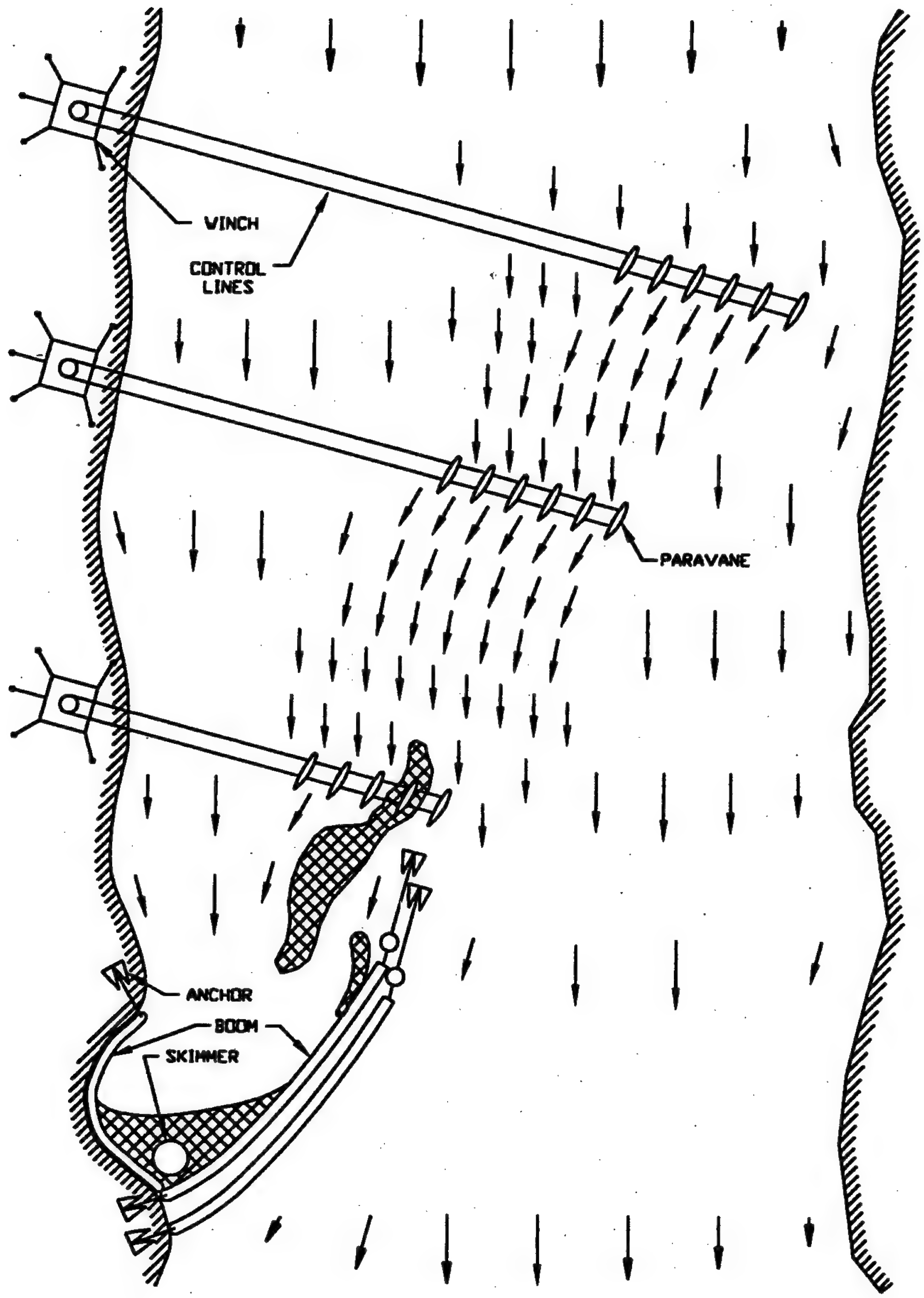
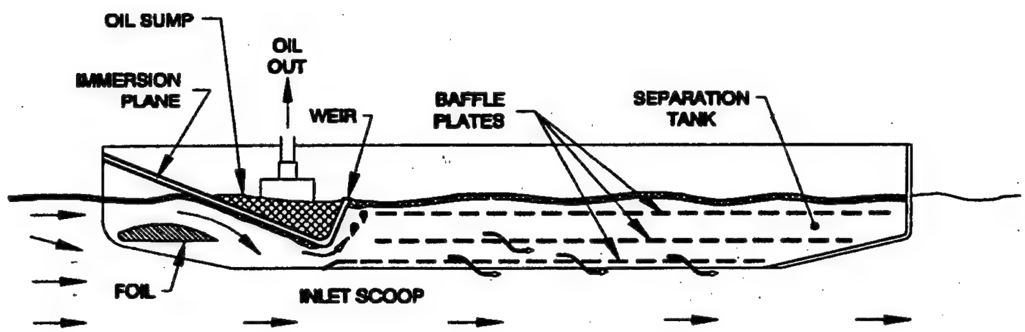


Figure M-1. Flow Diverters used in High Current used to Deflect Oil to Shore for Collection

Appendix N High Speed Skimmers

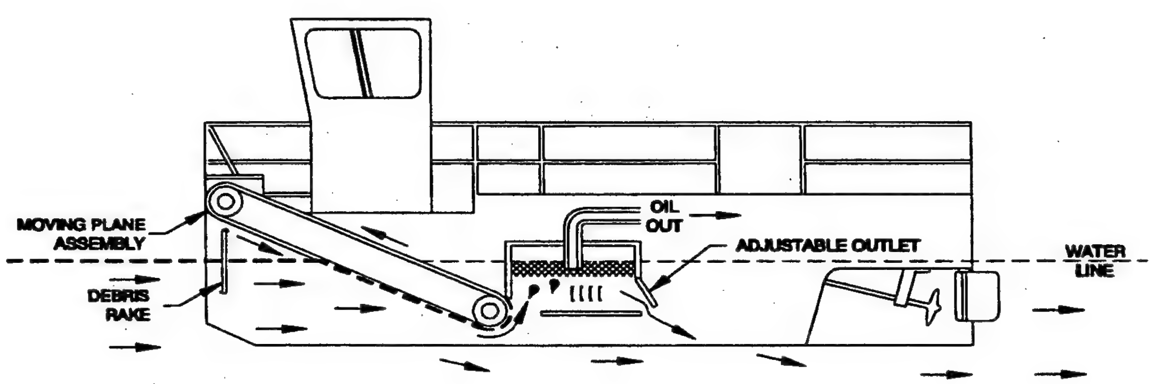
STATIC INCLINED PLANE



HIB R 20 LOA 20 ft.
Disp. 3,200 lbs.

HIB R 28 LOA 28 ft.
Disp. 3,878 lbs.

DYNAMIC INCLINED PLANE



USN DIP 3001 LOA 26 ft.

Figure N-1. Incline Plane Skimmers

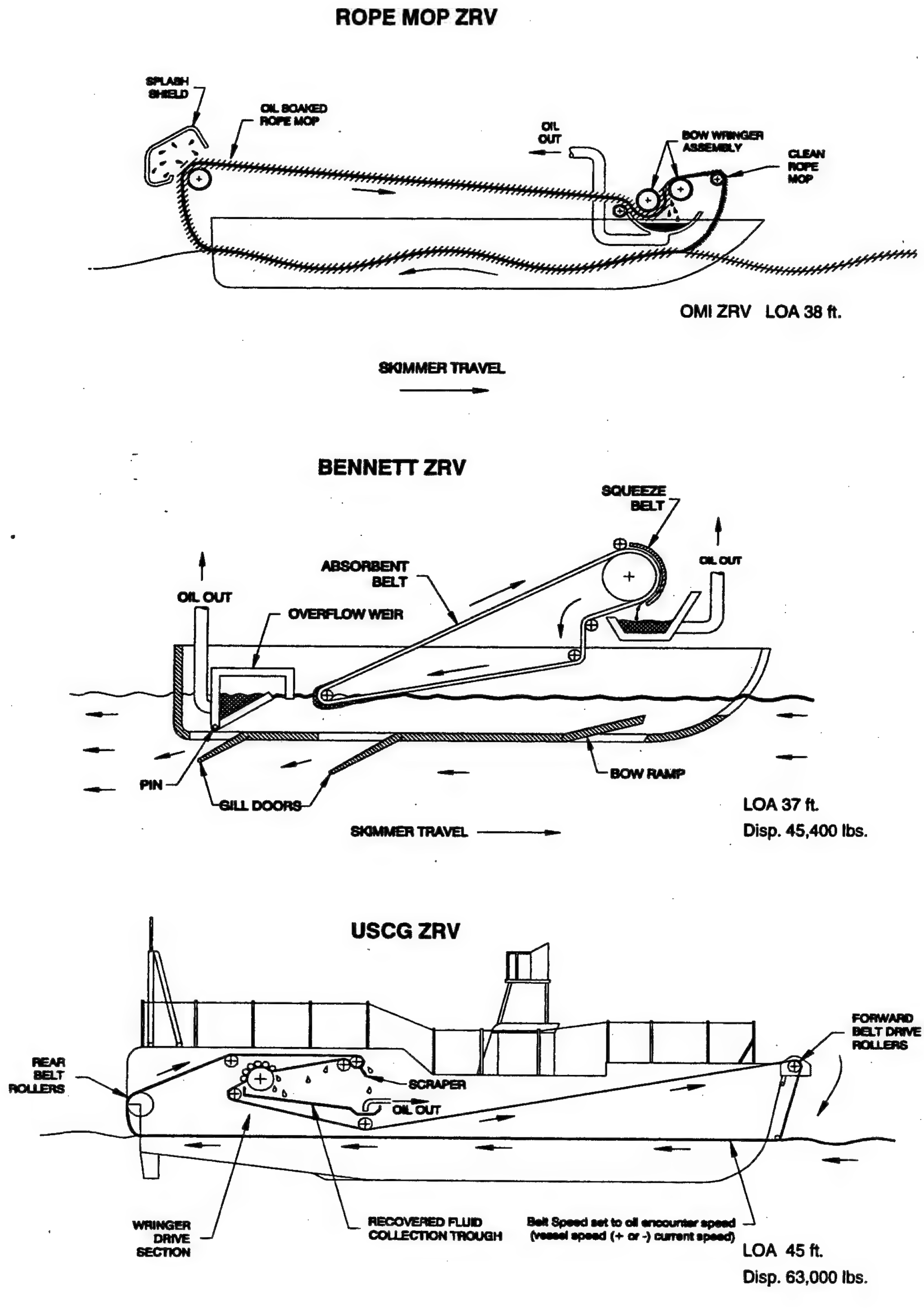


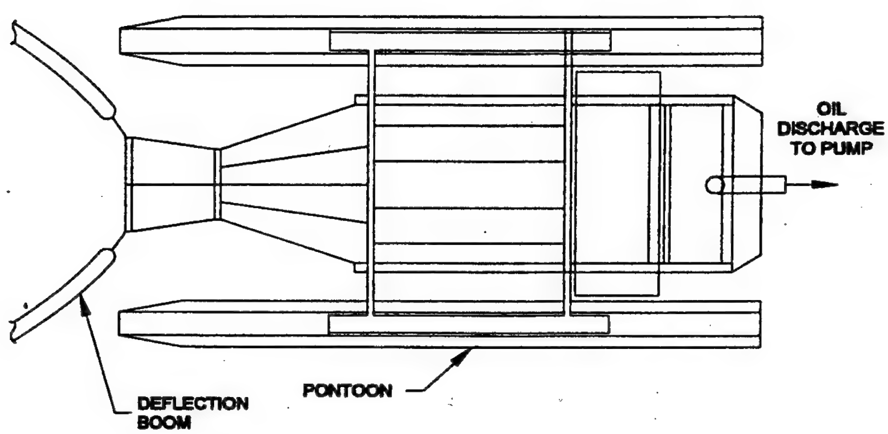
Figure N-2. Zero Relative Velocity (ZRV) Skimmers

EXPANSION WEIR

MINI FASFLO: LOA 6.9 ft.
Disp. 198 lbs.

FASFLO: LOA 13.2 ft.
Disp. 770 lbs.

TOP VIEW



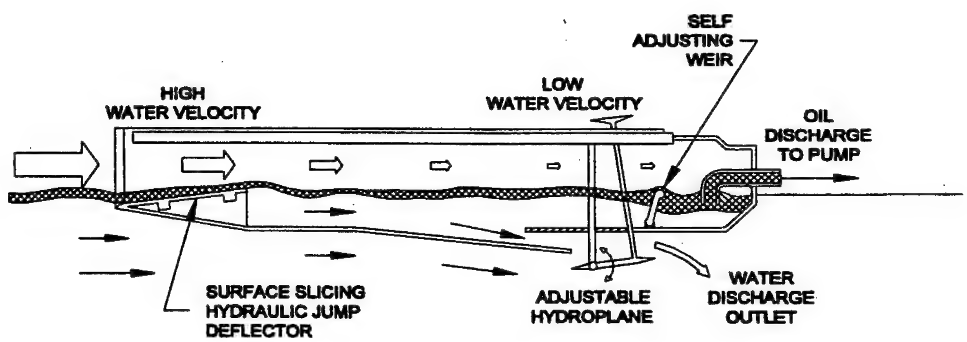
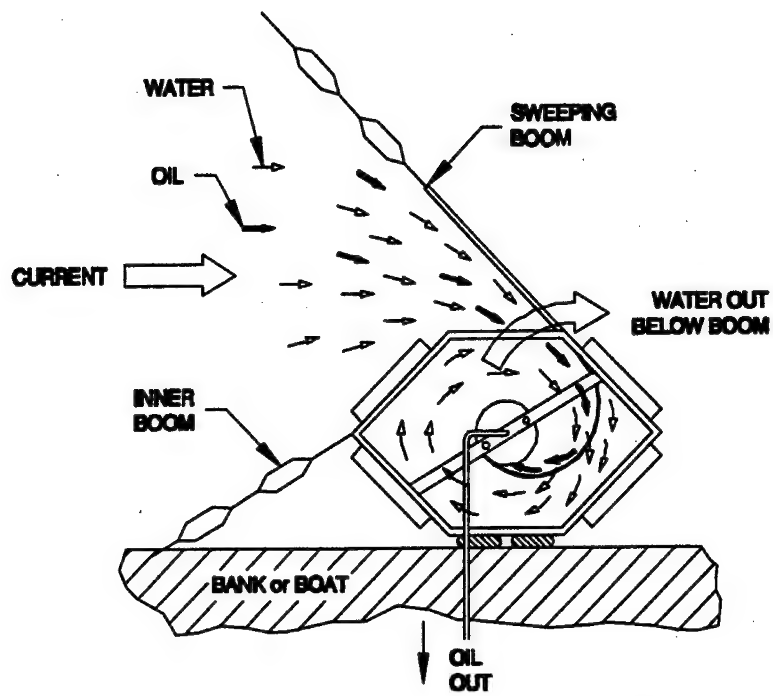


Figure N-3. Quiescent Zone Expansion Weir Skimmer

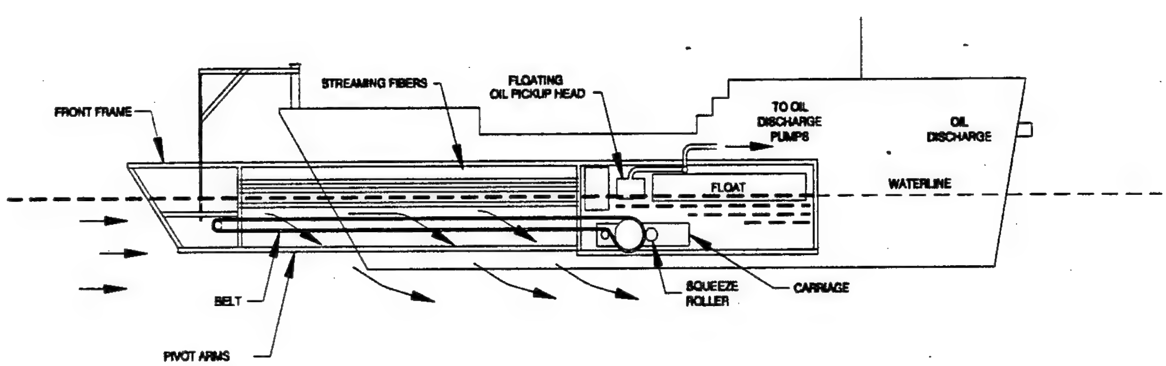
BLOMBERG CIRCUS (TOP VIEW)



Inshore/River: LOA 5.6 ft.
Disp. 286 lbs.

Offshore/Coastal: LOA 12.1 ft.
Disp. 440 lbs.

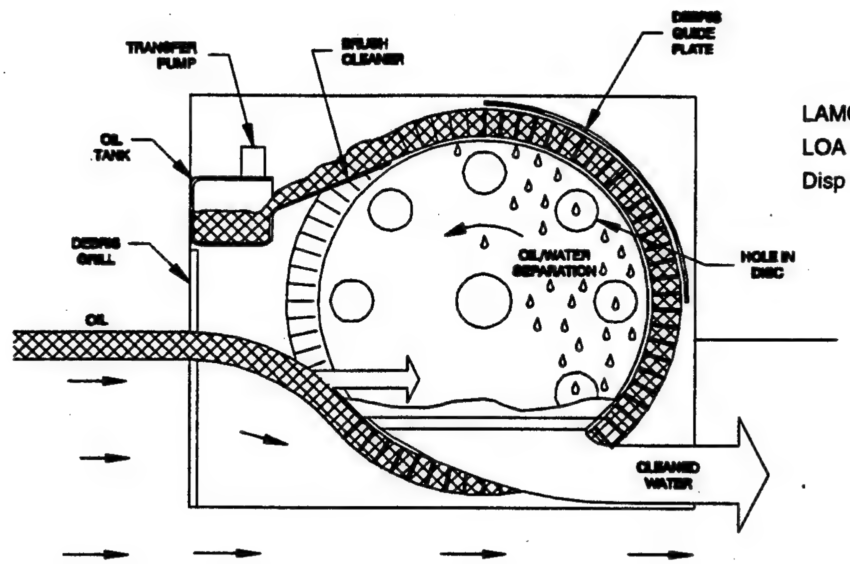
STREAMING FIBER SKIMMER



LOA 38.5 ft.
Disp. 44,800 lbs.

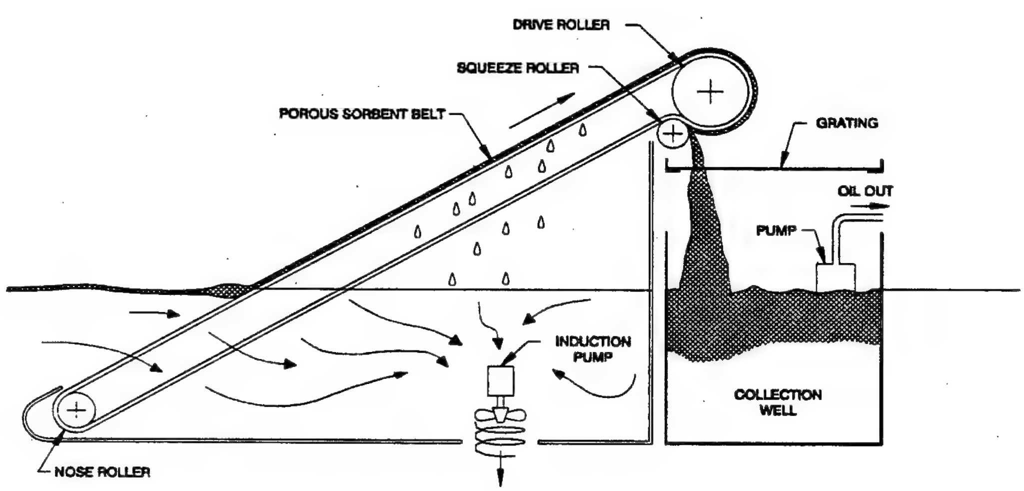
Figure N-4. Quiescent Zone; Hydrodynamic Circus and Streaming Fiber Skimmers

ROTATING BRUSH WHEEL



LAMOR
LOA 7.3 ft.
Disp 1,276 lbs.

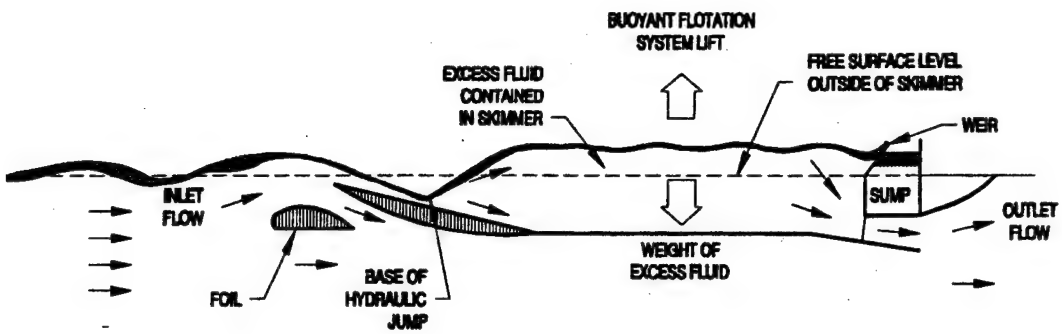
FILTER BELT



MARCO CLASS V   LOA 36 ft
Disp 16,480 lbs

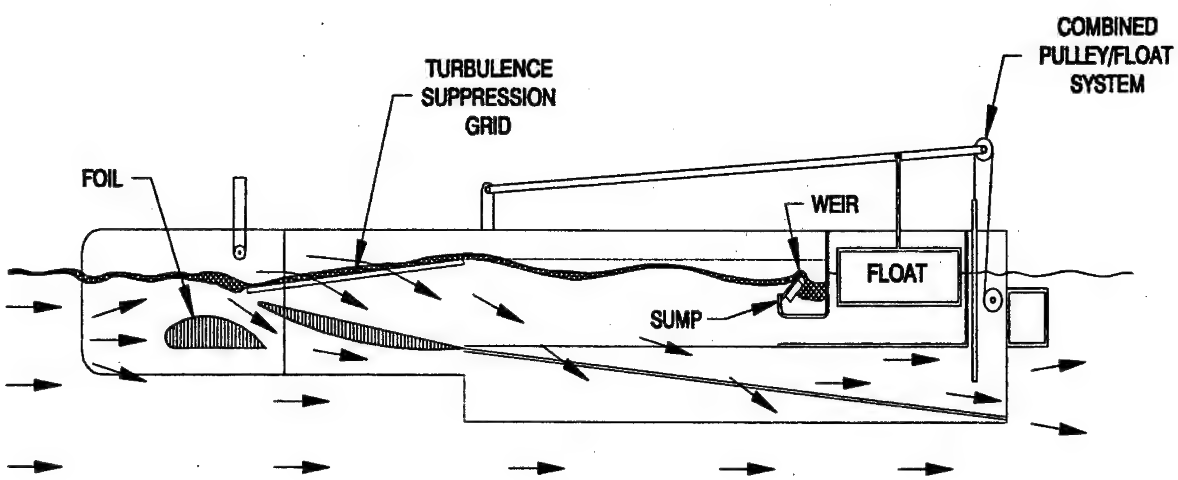
Figure N-5. Rotating Brush Wheel and Filter Belt Skimmers

HIGH CURRENT OILBOOM SKIMMER



1/3rd Scale Model LOA 16 ft.

STREAMLINED OIL BOOM SKIMMER



LOA 34 ft.

Figure N-6. Surface Slicing Skimmers

APPENDIX O Training Course Information and Summary

Inland Waters Oil Spill Response

DOWCAR Environmental Management, Inc.,
Taos, New Mexico

Tuition: $995
Length: 51 hours/ 5 days
Field/Classroom (hours): 29/21
Telephone: (505) 751-3688

Focus: A comprehensive program addressing safety, response effort management, equipment selection, and equipment deployment.

Application to fast water environments:
Fast water boom deployment techniques
River boom deployment exercise
Fast river boom deployment exercise
The course is offered at several locations around the country where fast water rivers are available for field exercises.

Classroom topics:
Applicable government regulations
Incident command system
Properties of oil/hazardous substances
Boom design and construction
Toxicological terminology and behavior
Oil sorbents and chemical agents
Protective breathing apparatus
Field monitoring and detection techniques
Oil skimmer selection and use
Spills on land – containment and cleanup techniques
Chemical protective clothing
Oil spill scenario group problem – table top exercise
Documentation procedures
Contingency planning
Ice and snow oil spill containment and recovery

Field Topics:
Calm/open water boom deployment techniques
Rope knot-tying exercise. Boat handling exercise.
Calm/open water boom deployment exercise
Fast water boom deployment techniques
River boom deployment exercise
Decontamination and termination procedures
Oil skimmer demonstration.
Personal protective equipment and clothing demonstration
SCBA exercise. PPE – level b/c decontamination exercise
Small streams/ditch spill response exercise
Fast river boom deployment exercise
Oil hazardous substance spill simulation exercise

Freshwater Oil Spill Control

Center for Marine Training and Safety
Texas A&M University
Galveston, TX

Tuition: $975
Length: 40 hours/ 5 days
Field/Classroom (hours): 20/20
Telephone: (409) 740-4850

Focus: This course provides the essential information for managing a spill response effort in rivers, small streams, on land and sub-surface.

Application to fast water environments:
Boom deployment operations
Movement containment and clean-up of oil
Containing and recovering oil on surface water
Skimmer operations

Classroom topics:
Contingency planning and response team training
Movement containment and clean-up of oil
Boom and skimmer design
Oil spill contractors and cooperatives
Preventing oil spills
Oil sampling and documentation techniques

Field Topics:
Shoreline protection, clean-up and restoration
Oil recovery from soil and oily debris disposal
Containing and recovering oil on surface water
Boom deployment and operations
Skimmer operations
Oil spill simulation exercises

Freshwater Oil Spill Refresher

Center for Marine Training and Safety
Texas A&M University
Galveston, Texas

Tuition: $650
Length: 24 hours/ 3 days
Field/Classroom (hours): 18/6
Telephone: (409) 740-4850

Focus: This course emphasizes reviewing spill response techniques through field exercises. Note that the prerequisite to this course is either completion of the Freshwater Oil Spill Control course or demonstrable experience.

Application to fast water environments:
Cascade booming
Vessel/rig enclosure
Mobile booming
Skimmer and crude oil exercise

Classroom topics:
Containment and cleanup strategy and tactics
Boom and skimmer designs and functions
NIIMS ICS
Communication exercise
Decontamination, PPE and HAZPOWER issues
Sorbents and chemical agents
NRDA and shoreline assessment issues

Field Topics:
Multiple boom deployment operations:
Cascade booming
Vessel/rig enclosure
Mobile booming
Skimmer and crude oil exercise
Mobile skimming operations
Large scale simulated release exercise

Inland Oil Spill Response and Safety

National Spill Control School
Texas A&M University
Corpus Christi, TX

Tuition: $795
Length: 40 hours/ 5 days
Field/Classroom (hours): 24/16
Telephone: (512) 980-3333

Focus: This field-oriented course presented in non-technical language addresses responder safety and spill response in rivers, lakes, streams, and groundwater.

Application to fast water environments:
Boat handling and water safety in rivers and streams
Boom deployment and recovery in flowing water
Cascade booming and corralling of oil

Classroom topics:
Skimmer and pump selection
Shoreline protection
Spill responder safety
Personal protection equipment and clothing
Shoreline clean-up
Groundwater remediation techniques and instrumentation
Respiratory protection
Decontamination of personnel and equipment
Constructing shoreline storage devices
Containment of oil on land
Underflow dams

Field Topics:
Boat trailer operation
Boating safety
Boom deployment and recovery in flowing water
Cascade booming and corralling of oil
Shore-based skimming
On-water skimming
Equipment clean-up and storage